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# APPLIED RESEARCH ON IMPLEMENTATION AND USE OF LIST PROCESSING LANGUAGES

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## ABSTRACT

This final report on Contract No. AF19(628)-5026 contains a summary of the five major tasks performed during the one-year duration of the contract. The work performed consisted of: 1) a variable-precision floating-point package for the solution of problems requiring very high precision, 2) extension of and improvements to the software system developed under an earlier contract, 3) assistance in the implementation and validation of a LISP Compiler, 4) development of a program for powerful manipulation of symbolic text (TECO), and 5) specification of a set of generalized display routines for visual communication with the computer. All work done related to the M-460 research computer at AFCRL.

## CONTENTS

## Appendix A

### VARIABLE PRECISION FLOATING-POINT PACKAGE

## I. SUMMARY OF OBJECTIVES

A. Investigate and evaluate techniques for the implementation of processors for list-processing languages. Consider possible extensions to, in particular, the LISP language, and investigate the corresponding problems of implementation.

B. Study techniques, including use of visual display devices for facilitating convenient interaction between an on-line user and a computer system. Extend the techniques for on-line debugging and program modification already in use in the AFCRL LISP system.

C. Apply the results of these studies to the implementation of a "second-generation" version of the on-line LISP list-processing system currently in operation on the AN/USQ-17 computer at AFCRL. Develop techniques for the convenient modification and updating of this programming system.

## II. SUMMARY OF TASKS PERFORMED

### Variable-Precision Floating-Point Package

Some problem areas in the Data Sciences Laboratory require the use of floating-point operations with very high precision. Although routines were available for floating-point operations on the M-460, the 45-bit mantissa available with these routines did not provide sufficient precision. Hence a new set of routines allowing indefinite precision was designed and constructed.

The range of numbers dealt with by these routines was not increased; 14 bits for the exponent plus a single sign bit was still utilized. The precision is indefinitely extensible, however, in increments of 30 bits beyond the minimum 45-bit mantissa. A total of 14 routines comprise the package, including routines for addition, subtraction, multiplication, division, comparison, conversion to and from fixed-point form, moving, input and output. Other functions available in the package, such as shifting, normalizing and conversion from signed magnitude to 1's complement form, are intended primarily for use by the more user-oriented routines mentioned above; but they may also be used by the programmer for more sophisticated operations.

Each routine determines the precision required for that operation by a number in one of the index registers (b6) on entry to the routine. This number represents the number of full computer words (of 30 bits each) necessary to contain the mantissa beyond the minimum 45 bits. Other index registers contain other parameters appropriate to the particular routines.

The division operation is the only exception to the variable-precision nature of the package. Since the problem areas for which the routines were constructed did not require division and the implementation problems were considerable, a single-precision (45-bit) routine was prepared to be compatible with the rest of the package, i.e., coded in the RAP language with similar calling sequences, word formats and general conventions.

The input-output routines do not communicate directly with peripheral devices but, rather, with a character buffer which in turn is utilized by the general I/O routines in the M-460 software such as "typel" and "flexinl". Completely general format is permitted allowing for decimal exponential notation, integer, fixed-point, etc.

A separate group of routines was also prepared for single-precision floating-point numbers. This was felt to be desirable because of the considerable saving in speed possible with single-precision floating-point arithmetic by using separate routines rather than the single-word case of the variable-precision routines. These routines have calling sequences identical to their variable-precision counterparts so that a user program could be checked out with the single-precision routines, then expanded by merely changing the names of the routines called.

Updated and expanded documentation of this package is given in Appendix A to this report.

## M-460 Assembly Language System

As a result of work done under a previous contract, many basic software routines were available for providing such necessary functions as editing symbolic source programs, assembling, loading and linking separately assembled subprograms, debugging in symbolic language using the on-line flexowriter, using magnetic tape for memory dumps, etc. The system developed to control all of these functions had many inadequacies which required substantial work during the course of this contract in order to have available a smoothly-running, efficient and well-integrated system.

In addition to innumerable small tasks performed on a day-by-day basis to improve operation of the entire software package, such functions were performed as preparing library tapes containing certain system subroutines for use by applications programs independently of the system, relocating portions of the system to various areas of core memory, making a minimum form of the FILER to be used independently of the remainder of the system, and adding some primitive TIC-like functions to the FILER. Several other features were added to the FILER to facilitate the simultaneous use of all magnetic tape units for speedier operation and allow for the use of multiple copies of a file with a given name on one reel of tape. The latter features and associated command characters are described in Appendix B to Quarterly Status Report No. 2.

LISP Implementation

Assistance was given to members of the AFCRL research staff in the implementation of the LISP compiler on the M-460. This work included editing and compiling portions of the compiler written in the LISP language using the previous version of the compiler, checking out the results of compilation, etc.

TECO

A program named TECO (Tape Editor and Corrector) was developed using specifications for similar programs written for the PDP-1 and PDP-6. This program will permit the use of the Type 340 display device attached to the M-460 for program debugging and updating dealing with generalized text strings. Of particular interest is the ability to operate flexibly on LISP statements with visual verification of the manipulations performed.

TECO uses an on-line command language (which permits macro definitions, conditionals, etc.) to control input-output as well as text operations. The macro larguage allows the most sophisticated search, match and substitution operations as well as simple typographical corrections to text.

Although the existing input-output routines in the M-460 software system have been used to the maximum extent possible, it was necessary to develop new routines for use of the display device. This work was performed in conjunction with the generalized display routines described below.

## Generalized Display Package

The Type 340 display device interfaced to the M-460 enables powerful graphical techniques to be used for on-line problem solving. Both line-drawing (using incremental vector hardware) and alphanumeric (using character generation hardware) facilities may be used to great advantage in the preparation and checkout of list-oriented programs.

Sinc the specific techniques to be used will be determined largely by experimentation, it is desirable to have a flexible system within which many graphical techniques can be investigated. Specifications were prepared for a set of primitive routines to perform the necessary functions of display initiation and regeneration, display buffer maintenance, object identification, simple object generation (points, lines, circles, characters, etc.), light-pen identification, and utilization of hardware features of intensity control, character angle control, etc. These routines will be implemented under a separate contract.

## III. PERSONNEL AND PUBLICATIONS

### Personnel

The following personnel of Adams Associates have been the principal participants in the work done under this contract:

| | |
|---|---|
| Roy M. Salzman | Supervisory Analyst |
| Donald E. Ellis | Programmer Analyst |
| John S. Hermistone | Programmer Analyst |
| Thomas A. Flaherty | Senior Programmer |
| Marlene E. Ponton | Senior Programmer |

### Publications

Other than the Quarterly Status Reports and this final report, no publications have been required by or produced under the terms of this contract.

# APPENDIX A

# VARIABLE PRECISION FLOATING-POINT PACKAGE

## I. INTRODUCTION

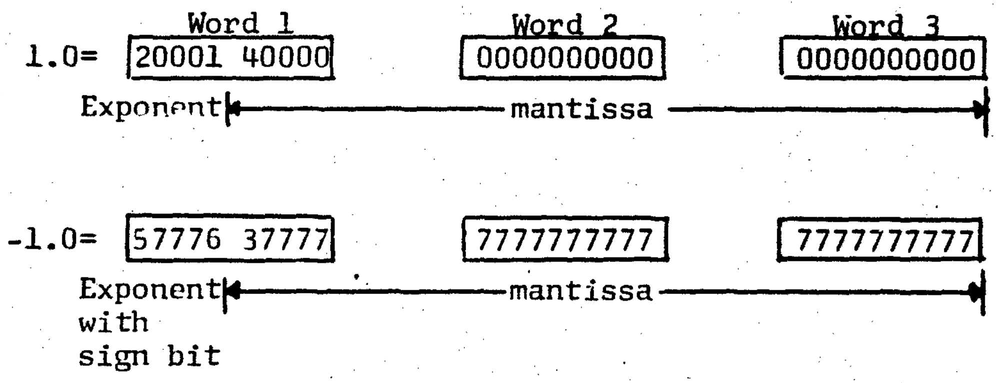
The original floating-point arithmetic package for the Univac 460 allowed for a 14-bit exponent, 45-bit mantissa and a single sign bit. Since precision permitted by the size of the mantissa was not adequate for some problems, a variable-precision package was developed to provide basically the same arithmetic functions but with no limit on the length of the mantissa. The only function not available in the variable-precision version is floating-point division. This operation is available in the package as a single-precision routine with similar conventions since no need could be seen for variable precision in this operation. Input and output routines have also been added to facilitate communication between the package and the user routines.

The scale of the numbers which can be handled by this new package is the same as with the previous set of routines since the exponent and the basic mode of representation are unchanged.

## II. PROGRAM CHARACTERISTICS

### Number Representation

The floating-point binary number format used is a 1-14-n format with one common sign bit indicating the sign of the total numerical quantity, a 14-bit exponent with a bias of $20000_8$, and an n-bit mantissa where n=30(m)+15; m=1,2,3,---. Thus each floating-point number requires m+1 30-bit storage registers. The mode of representation is 1's complement rather than the more usual signed magnitude representation. Using this mode, a negative floating-point number is a complete 1's complement of its positive counterpart. The number format may be diagrammed as follows:



### Summary of Routines

| | |
|---|---|
| FLAD | - floating-point addition |
| FLSB | - floating-point subtraction |
| FLTMUL | - floating-point multiplication |
| FLTDV | - floating-point division |

FLTCOM - floating-point comparison<br>
FLTFIX - floating-point to fixed-point conversion<br>
FXTFLT - fixed-point to floating-point conversion<br>
NUMIN - input a floating-point number from a packed buffer<br>
NUMOUT - output a floating-point number to a packed buffer<br>
FLTMOV - move a floating-point number from one area to another<br>
CTOSM - convert from signed magnitude to 1's complement<br>
RSHIFT - right shift a floating-point number and adjust exponent<br>
LSHIFT - left shift a floating-point number and adjust exponent<br>
FLTNORM - normalize a floating-point number<br>
GET1 - input a single character from a packed buffer<br>
PUT1 - output a single character to a packed buffer

The first nine of the above routines would normally be used by the application programmer to perform floating-point arithmetic and input-output operations. The last seven routines may also be used, but their primary purpose is to perform appropriate utility functions for the first nine.

## Calling Sequence Convention

The basic input arguments to the primary (first nine) sub-routines are contained in the A and Q registers upon entry to the routine. Normally, A contains the address of the first operand, Q the address of the second operand, and C(FLTN) the number of words required for the mantissa of the operands. In the case of fixed-point to floating-point conversion, b7 contains the binary-point position of the fixed-point quantity.

Output of the arithmetic function routines (FLAD, FLSB, FLTMUL, FLTDV) is left in registers AF through AF+C(FLTN). The C(FLTN) is never altered by the subroutines and therefore need not be set up before every call. It should be set initially and at such time as the length of the data changes.

## III. SUBROUTINE DESCRIPTIONS

The 16 subroutines referred to above are described in detail on the following pages.

## FLAD

### Function

To add two floating-point numbers of variable length (format 1-14-m) and store the normalized sum in a common storage area.

### Calling Sequence

```
lda   x
ldq   y
rj    flad
(normal return)
```

### Input

x - address of first word of X
y - address of first word of Y
n - number of words - 1 stored in FLTN

### Output

Z(1)-Z(n+1) - floating-point sum of X and Y stored in AF(1)-AF(n+1).

### Subroutines Used

CTOSM, FLTNORM, FLTMOV, RSHIFT

### Storage Areas Read

X(1) - X(n+1), Y(1) - Y(n+1), FLTN

### Storage Areas Written

AF(1)-AF(n+1), SIGN, SIGN1, SIGN SWITCH, FLTNUM(1)-FLTNUM(n+1), FLTEXP, AFSIGN

Method

1. Convert addends to signed magnitude format.

2. Calculate a shift factor k
   $t = |\exp(x)| - |\exp(y)|$

   $k = |t|$

3. Shift smaller addend right k places in order to line up binary point.

4. Set

   $x = a_1 2^{-15} + a_2 2^{-30} + \ldots + a_m 2^{-15m}$

   $y = b_1 2^{-15} + b_2 2^{-30} + \ldots + b_m 2^{-15m}$

   where

   $m = 1$ to $(2n+1)$

5. Add (for range of m)

   $W_m = b_m 2^{-15} + a_m 2^{-15m}$

   set $W_0 = 0$

6. Combine W's to form sum z

   for $m = (2n-1)$ to $1$; $r$ = overflow

   $z_{\frac{m+1}{2}} + r_{\frac{m+1}{2}} = W_{m-1} 2^{-15} + W_m + r_{\frac{m+1}{2}}$

   for $m = 2n+1$

   $z_{n+1} + r_{n+1} = W_{2(n-1)} 2^{-15} + W_{2n+1}$

7. If $r_1$ is equal to zero, go to step 8.
   If $r_1$ is not equal to zero, shift entire sum right and adjust exponent accordingly.

8. Insert exponent

   $z_1 + \exp(z) \cdot 2^{-15} \longrightarrow z_1$

9. Convert addends back to 1's complement.

10. Normalize sum.

Error Conditions

If the exponent of the result z exceeds 37777, control is transferred to "flterror." A STOP 4 halt will result and the address at which the error occurred will appear in the A-register.

# FLSB

## Function

To subtract one variable-length floating-point number (format 1-14-m) from another of the same length and store the normalized difference in a common storage area.

## Calling Sequence

```
lda   x
ldq   y
rj    flsb
(normal return)
```

## Input

x - address of first word of X
y - address of first word of Y
n - number of words - 1 stored in FLTN

## Output

Z(1)-Z(n+1)- floating-point difference of X and Y stored in AF(1)-AF(n+1).

## Subroutines Used

FLAD

## Storage Area Read

X(1) - X(n+1), Y(1) - Y(n+1), FLTN

## Storage Area Written

AF(1)-AF(n+1)

Method

1. Complement floating-point number y.
   Save original sign.

2. Go to add x and y (see FLAD for method).

3. Restore y to original sign.

Error Conditions

None except those provided by FLAD.

## FLTMUL

### Function

To multiply two floating-point numbers of variable length (format 1-14-m) and store the normalized result in a common storage area.

### Calling Sequence

```
lda   x
ldq   y
rj    fltmul
(normal return)
```

### Input

x - address of first word of X
y - address of first word of Y
n - number of words - 1 stored in FLTN

### Output

Z(1)-Z(n+1) - floating-point product of X and Y stored in AF(1)-AF(n+1)

### Subroutines Used

CTOSM, FLTNORM

### Storage Areas Read

X(1) - X(n+1), Y(1) - Y(n+1), FLTN

### Storage Areas Written

AF(1)-AF(n+1), FLTNUM(1) - FLTNUM(2n+1), SIGN

Method

1. Let $x = a_1 2^0 + a_2 2^{-15} + a_3 2^{-45} + \ldots + a_t 2^{-15(2t+3)}$

$t \neq 0,1$
$t = 2-(n+1)$

Let $y = b_1 2^0 + b_2 2^{-15} + b_3 2^{-30} + \ldots + b_3 2^{-15(s-1)}$

$s \neq 0,1$
$s = 2-2(n+1)$

2. Then for $i = 1$ to $s$

$j = 1$ to $t$

calculate

$$2b_i \left( \frac{a_j - 1}{2} \right) + b_i = C_k$$

$$C_k = d_1 2^0 + d_2 2^{-15} + d_3 2^{-30}$$

3. If $j = 1$ or $2$

set: $f_{i+j-1} = d_1 2^0 + f_{i+j-1}$

$f_{i+j} = d_2 2^{-15} + f_{i+j}$

$f_{i+j} = d_3 2^{-30} + f_{i+j+1}$

4. if $j \neq 1$ or $2$

set: $f_{i+j} = d_1 2^0 + f_{i+j}$

$f_{i+j+1} = d_2 2^{-15} + f_{i+j+1}$

$f_{i+j+2} = d_3 2^{-30} + f_{i+j+2}$

5. Sum intermediate results

$$Z_{n+1} + r_1 + f_{2n+1}2^{-15} + f_{2n}$$

$$Z_n + r_2 = f_{2n-1}2^{-16} + f_{2n-2} + r_1$$

$$\vdots$$

$$Z_1 = f_1 + r_{n+3}$$

Notes

1. Length of input is limited only by amount of storage reserved for a working area. Presently the maximum word length is 10.

2. To avoid an error, both words should occupy the same amount of storage. If one input value is shorter, it should be filled with zeros.

Error Conditions

None.

## FLDV

### Function

To divide a pair of floating-point numbers each of length 2 (format 1-14-45) and store the normalized result in a common storage area (AF,AF+1).

### Calling Sequence

```
lda    x
ldq    y
rjp    fldv
(normal return)
```

### Input

x - address of first word of X
y - address of first word of Y

### Output

Z(1),Z(2) - floating-point quotient of X/Y stored in AF,AF+1

### Subroutines Used

CTOSM

### Storage Areas Read

X, X+1, Y, Y+1

### Storage Areas Written

AF,AF+1, DVHP1, DVHPR1, DVHP2, DVHPR2, FLTNUM, FLTNUM+1

## Method

1. Change representation to signed magnitude.

2. Compute exponent by subtraction.

3. If $X = 0$ go to step 9

4. If $Y = 0$ go to step 10

3. Separate divisor, Y, into two signed words Y1, Y2

$$Y = Y1 + Y2$$

4. Divide X value by Y1

$$X/Y1 = X1 + \text{remainder}$$

5. Divide remainder by Y1

$$\frac{Rem}{Y1} = X2$$

6. Get correction

$$\frac{2(X1)Y2}{Y1}$$

7. Set result

$$Z = X1 + X2 + \text{bias} - \frac{2(X1)Y^2}{Y1}$$

8. Store result in AF,AF+1, two's complement. Return to user.

9. Set AF,AF+1 to 0 and exit.

10. Set AF,AF+1 = $\pm\alpha$ depending on X; exit.

# FLTCOM

## Function

To compare arithmetically two variable-length floating-point numbers (format 1-14-m). Control is returned to one of the three locations following the call depending on the relationship between the numbers.

## Calling Sequence

```
lda   x
ldq   y
rj    fltcom
(return 1 if x < y)
(return 2 if x = y)
(return 3 if x > y)
```

## Input

x - address of first word of X
y - address of first word of Y
n - number of words - 1 stored in FLTN

## Output

None

## Subroutines Used

FLSB, LSHIFT

## Storage Areas Read

X(1)-X(n+1), Y(1)-Y(n+1), FLTN

## Storage Areas Written

FLTNOT

lethod

1. Check X and Y for like signs.

2. If signs are not alike, choose positive value as the greater and transfer control to proper return.

3. If signs are alike and positive, calculate K.

   K = exp(x)-exp(y)

   a. if K < 0 then X < Y

   b. if K > 0 then X > Y

   c. if K = 0 then go to FLSB

      subtract:

      X-Y = Z

      if Z > 0 then X > Y

      if Z < 0 then X < Y

      if Z = 0 then X = Y

   d. transfer control to proper return

4. If signs are alike and negative, complement both values. Then calculate K.

   K = exp(x)-exp(y)

   a. if K < 0 then X > Y

   b. if K > 0 then X < Y

   c. if K = 0 then go to FLSB

      subtract

      X-Y = Z

      if Z < 0 then X > Y

      if Z > 0 then X < Y

      if Z = 0 then X = Y

d. Restorc original signs of input

e. Transfer control to proper return

Error Conditions

None.

# FLTFIX

## Function

To convert a variable-length floating-point number (format 1-14-m) to a fixed-point number and store the binary point β.

## Calling Sequence

```
lda   x
ldq   y
rj    fltfix
(normal return)
b7 contains the binary point (β) on return
```

## Input

x - address of first word of floating-point number X to be converted

y - address of first word of area into which fixed-point number Y should be stored

n - number of words - 1 stored in FLTN

## Output

β - binary point of number generated

Y(1)-Y(n+1) fixed-point X

## Subroutines Used

LSHIFT, FLTMOV, CTOSM

## Storage Areas Read

X(1) - X(n+1), FLTN

## Storage Areas Written

SIGN, FLTNUM, Y(1) - Y(n+1)

## Method

1. Set X = |X|; save original sign.
2. Move input to f (working storage - FLTNUM)

   for m = 1-(n+1)

   $f_{m+1} = X_m$
3. Set $f = f \cdot 2^{-14}$ by shifting left 14 places. This left justifies the input in the area f(2) to f(n+2) with one bit remaining for sign.
4. Set $Y_m = f_{m+1}$ for m = 1 to (n+1).
5. Restore original sign of value.

## Error Conditions

None.

# FXTFLT

## Function

To convert a variable-length fixed-point number to a floating-point number in format 1-14-m. Output will be normalized.

## Calling Sequence

```
lda   x
ldq   y
ldb   β,,7
rj    fxtflt
(normal return)
```

## Input

x - address of first word of fixed-point number X to be converted
y - address of first word of converted number Y
n - number of words - 1 stored in FLTN
β - binary point of input

## Output

Y(1)-Y(n+1) - floating-point representation of input X.

## Subroutines Used

FLTNORM, FLTMOV, CTOSM

## Storage Areas Read

X(1)-X(n+1), FLTN

## Storage Areas Written

Y(1)-Y(n+1)

Method

1. Let $X = |X|$, save original sign.
2. Move input to working storage f.

   for $m = 1$ to $(n+1)$

   $$f_{m+1} = X_m$$

3. Set $\exp(f) = \text{bias} + 15$

   $$n = n+1$$

4. Insert exponent into first word of f-area

   $$f(1) = \exp(f) \cdot 2^{-15}$$

5. Normalize f area.
6. Restore original sign.
7. Transfer f-area to Y-area.

Error Conditions

None.

# NUMIN

## Function

To convert a floating-point number represented by a flex-code array to binary format floating-point number of specified length. Numin will accept any f[illegible]e format

```
12
12.0
12.
1.2E+1
1.2E1
120E-1          -100 < E < 100
```

A 77 code will delimit the array.

## Calling Sequence

```
lda   x
ldq   buffer
rj    numin
(error return)
(normal return)
```

## Input

```
buffer = starting address of flex-code array
     x = starting address of binary floating-point number
     n = number of words - 1 stored in FLTN
```

## Output

X(1)-X(n+1)

## Subroutines Used

GET1, FLTNORM, FLTMOV, FLTMUL, FLAD, POWER, CTOSM

Storage Areas Read

FLTN

Storage Areas Written

X(1)-X(n+1)

# NUMOUT

## Function

To convert a binary floating-point number to a flex-code array with integral and fractional portions specified and an exponent. A 77 will delimit the output buffer.

## Calling Sequence

```
lda     buffer
ldq     x
rj      numout
uandl   k,l
(error return)
(normal return)
```

## Input

buffer = starting address of flex-code array
x = starting address binary array
k = number of decimal places before decimal point
l = number of decimal place after decimal point
n = number of words -1 of input stored in FLTN

The length of the buffer LIM is determined by the input

$$LIM = \frac{K + L + 15}{5}$$

## Output

A flex-code buffer representing the floating-point number, stored in C(LIM) locations beginning at BUFFER and delimited by 77.

## Subroutines Used

CTOSM, FLTMUL, FLTMOV, FLTCOM, PUT1, FLTNORM

Storage Area Read

X(1)-X(n+1), FLTN

Storage Area Written

BUFFER(1) - BUFFER(LIM)

# FLTMOV

## Function

To transfer any string of words from one area to another.

## Calling Sequence

```
lda   x
ldq   y
rj    fltmov
(normal return)
```

## Input

x - starting address of area to be transferred
y - starting address of area to be filled
n - number of words to be moved - 1 stored in FLTN

## Output

Y(1)-Y(n+1)

## Subroutines Used

None

## Storage Areas Read

X(1)-X(n+1), FLTN

## Storage Areas Written

Y(1)-Y(n+1)

## Error Conditions

None

## CTOSM

### Function

To convert a 1's complement floating-point number to signed magnitude, or vice versa.

### Calling Sequence

```
lda   x
rj    ctosm
(normal return)
```

### Input

x - address of first word of floating-point number X
n - number of words - 1 stored in FLTN

### Output

X(1)-X(n+1) converted floating-point number.

### Subroutines Used

None

### Storage Areas Read

X(1)-X(n+1), FLTN

### Storage Areas Written

X(1)-X(n+1)

### Method

If X > 0 transfer control to user

2. If X < 0 set X = -X.

3. Invert sign bit.

## Error Conditions

None.

# RSHIFT

## Function

To shift a variable-length floating-point number (format 1-14-m) n places right (end off) and adjust the exponent accordingly.

## Calling Sequence

```
lda   x
ldq   k
rj    rshift
(normal return)
```

## Input

x - address of first word of floating-point number X
    to be shifted
n - number of words - 1 stored in FLTN
k - number of places to shift

## Output

X(1)-X(n+1) shifted input in same area

## Subroutines Used

CTOSM

## Storage Areas Read

X(1)-X(n+1), FLTN

## Storage Areas Written

RTEMP, RTEM1, RTEM2, IR2, RSH7

## Method

1. Set $K = k$.

2. If $k > 30$ set $k' = 30$ and $k = k-30$

   If $k \leq 30$ set $k' = k$ and $k = 0$

3. Let

   $$X = a_1 2^{-15} + a_2 2^{-30} + \ldots + a_{n+1} 2^{-15(n+1)}$$

   $$b_1 = a_1 2^{-15}$$

   $$b_2 = a_2 2^{-30}$$

   $$\vdots$$

   $$b_m = a_{n+1} 2^{-15(n+1)}$$

   $r$ = overflow

   for $m = n+1$

   $$C_m + r_m = b_m \cdot 2^{-k'}$$

   for $m = n$ to $0$

   $$C_m + r_m = b_m \cdot 2^{-k'} + r_{m+1}$$

4. Check $k = 0$. If $k = 0$ replace original input with C. Set exp = exp + K.

   If $k \neq 0$ return to step 3.

## Error Conditions

None.

# LSHIFT

## Function

To shift a floating-point number of variable length (format 1-14-m) a specified number of places left and adjust the exponent accordingly.

## Calling Sequence

```
lda    x
ldq    k
rj     lshift
(normal return)
```

## Input

x - address of first word of floating point number X to be shifted
n - number of words - 1 stored in FLTN
k - shift factor

## Output

X(1)-X(n+1) - shifted word replaces original input

## Subroutines Used

CTOSM

## Storage Areas Read

X(1)-X(n+1), FLTN

## Storage Areas Written

LSTEM, LSEXP, LSTEM2, LSEND

## Method

Same as RSHIFT routine except that K is positive rather than negative.

## Error Conditions

If at the end of shifting there is a remainder of non-zero, control will be transferred to FLTERROR. The address at which the error occurred will be shown in the A-register and a STOP 4 will occur.

## FLTNORM

### Function

To normalize a floating-point number of variable length (format 1-14-m). The first significant bit will be 0 if number is negative and 1 if number is positive. The exponent will be adjusted accordingly.

### Calling Sequence

```
lda   x
rj    fltnorm
(normal return)
```

### Input

x - address of first word of floating-point number X
n - number of words - 1 stored in FLTN

### Output

X(1)-X(n+1) a normalized floating-point number stored in area of input.

### Subroutines Used

LSHIFT, CTOSM

### Storage Areas Read

X(1)-X(n+1), FLTN

### Storage Areas Written

X(1)-X(n+1)

Method

1. Examine number starting with first word.
2. Inspect one bit at a time until reaching the first significant bit.
3. Index k at each check to determine a shift factor.
4. Go to LSHIFT with k as input.

## GET1

### Function

To unpack a specified buffer of 6-bit flex-code characters starting with the leftmost character and leave the character right justified in the A register in bci mode.

### Calling Sequence

```
rj   getl
(normal return)
```

### Input

GPOINT = starting address of buffer
GCHAR  = character (0-4) to start reading (left to right)

### Output

A - next 6-bit bci character
GPOINT, GCHAR - updated character position

### Subroutines Used

None

### Storage Areas Read

GPOINT, GCHAR TBCIFLX (table)

### Storage Areas Written

GPOINT, GCHAR

# PUT1

## Function

To pack a buffer, from left to right, with 6-bit characters converted to flex-code from bci.

## Calling Sequence

```
lda     k
jr      put1
(normal return)
```

## Input

```
PPOINT = starting address of buffer
PCHAR  = character (0-4) to start packing (left to right)
K      = six-bit flex-code character
```

## Output

A packed buffer of bci code
PPOINT, PCHAR - updated character position

## Subroutines Used

None

## Storage Areas Read

TBICFLX, PCHAR, PPOINT

## Storage Areas Written

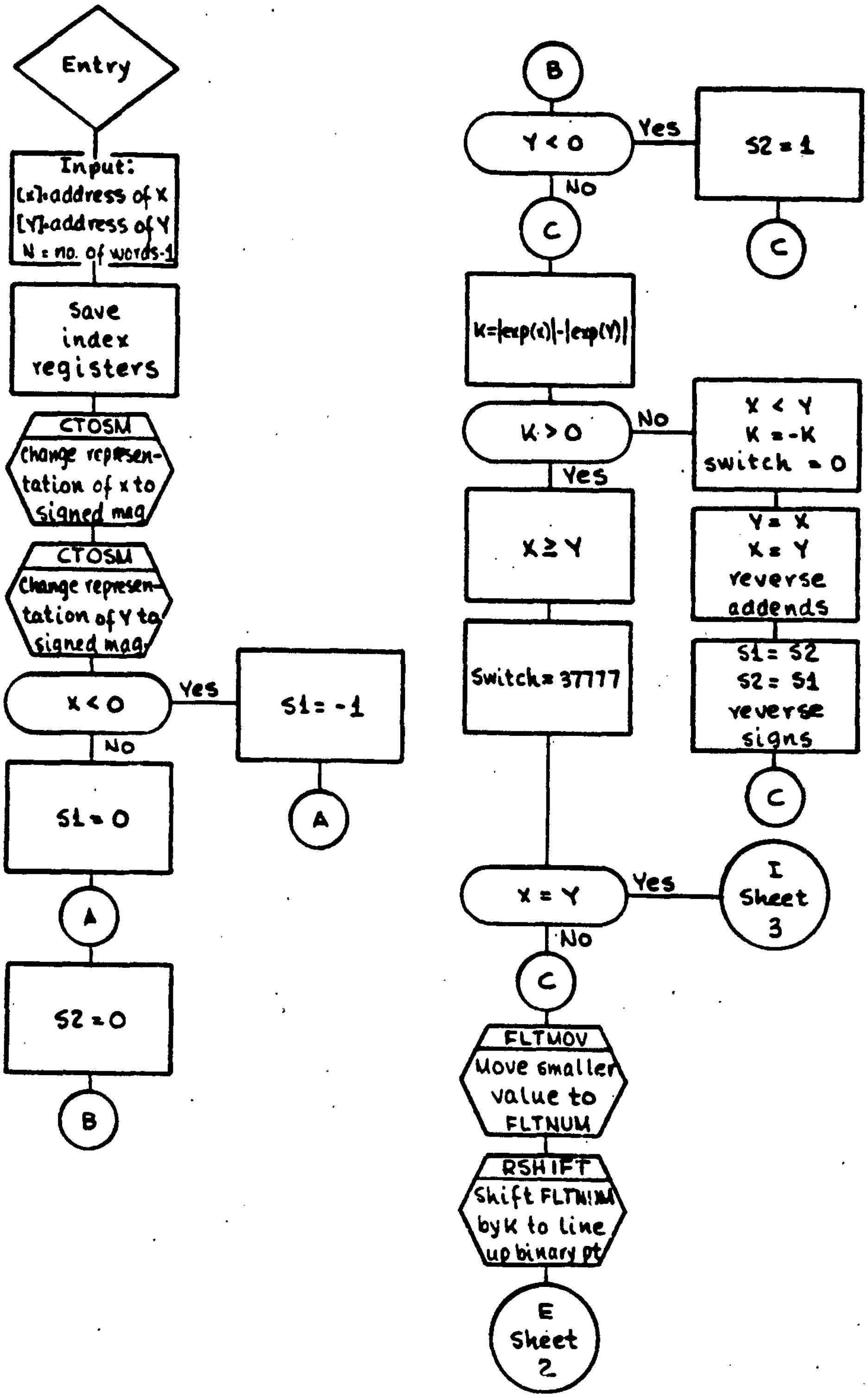
PCHAR, PPOINT

## IV. CONSTANTS

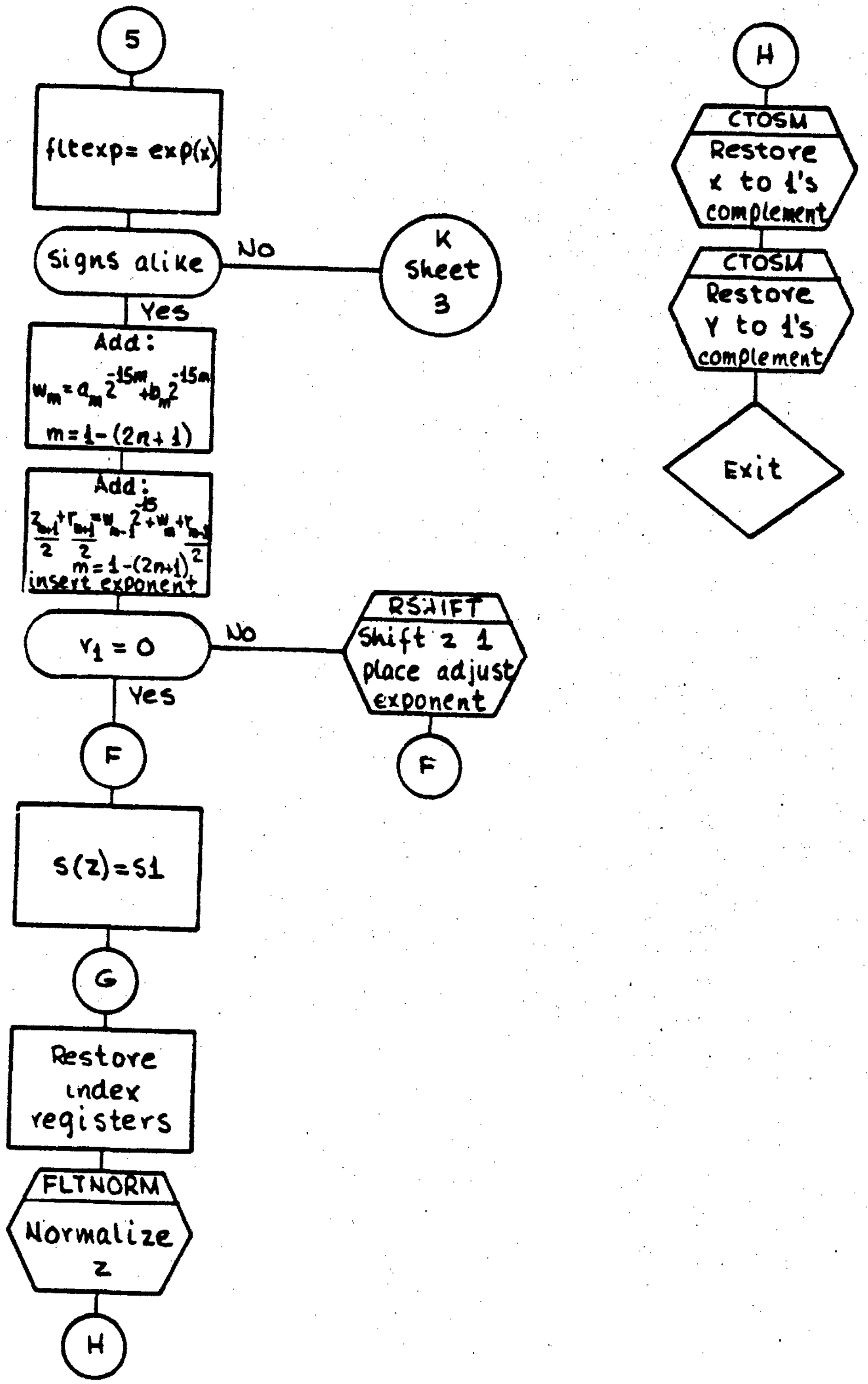
| Label | Value | Description |
|---|---|---|
| con4 | 40000·00000 | Used to set and complement the sign bit |
| con8 | 0000077777 | Used in subtract routine |
| con7 | 00001·00000 | Used to check overflow |
| inst1 | rj flad | Instruction switch used in 'flsb' |
| inst2 | jl flsh | Instruction switch used in 'flsb' |

## V. FLOW CHARTS

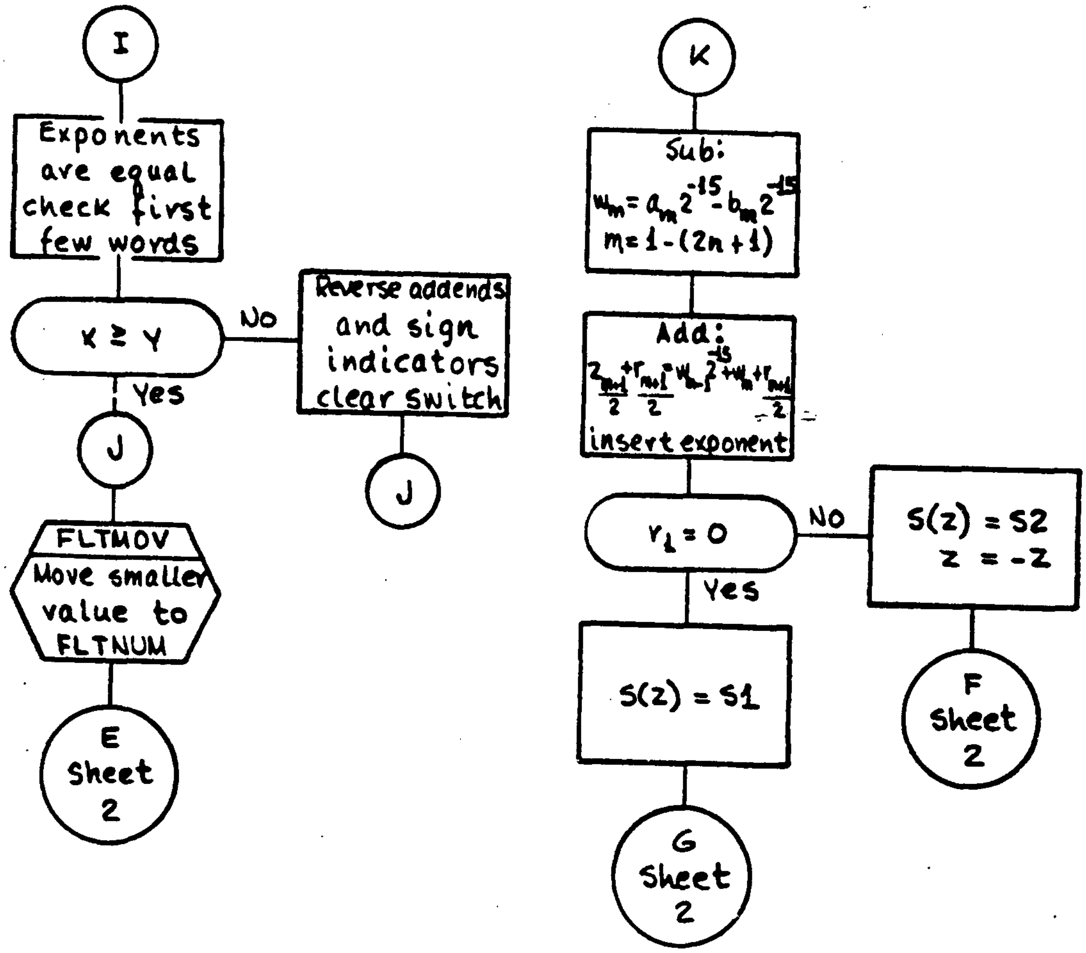
Flow charts for the subroutines described in the preceding section appear on the remaining pages of this appendix.



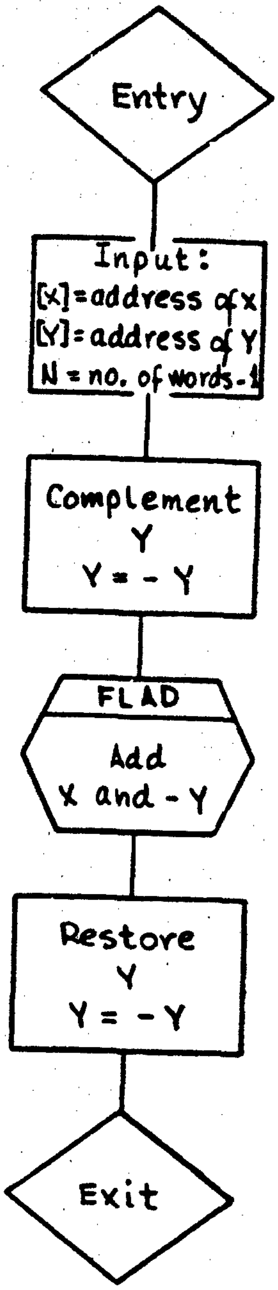
FLAD
Sheet 1 of 3


5
fltexp= exp(x)
Signs alike
No
K
Sheet
3
Yes
Add:
$w_m = a_m 2^{-15m} + b_m 2^{-15m}$
m=1-(2n+1)
Add:
$\frac{z_{m-1}}{2} + \frac{r_{m-1}}{2} = w_{m-1} 2^{-15} + \frac{w_m + r_{m-1}}{2}$
m=1-(2n+1)
insert exponent
$Y_1 = 0$
No
RSHIFT
Shift z 1 place adjust exponent
F
Yes
F
s(z)=s1
G
Restore index registers
FLTNORM
Normalize z
H
H
CTOSM
Restore x to 1's complement
CTOSM
Restore Y to 1's complement
Exit

FLAD
Sheet 2 of 3


I
Exponents are equal check first few words
x ≥ y
No
Reverse addends and sign indicators clear switch
J
Yes
J
FLTMOV
Move smaller value to FLTNUM
E Sheet 2
K
Sub:
$w_m = a_m 2^{-15} - b_m 2^{-15}$
$m = 1 - (2n+1)$
Add:
$z_{\frac{m+1}{2}} + r_{\frac{m+1}{2}} = w_{m-1} 2^{-15} + w_m + r_{\frac{m+1}{2}}$
insert exponent
$r_1 = 0$
NO
$S(z) = S2$
$z = -z$
F Sheet 2
Yes
$S(z) = S1$
G Sheet 2

FLAD
Sheet 3 of 3


Entry
Input:
[X]=address of X
[Y]=address of Y
N = no. of words-1
Complement
Y
Y = - Y
FLAD
Add
X and - Y
Restore
Y
Y = - Y
Exit

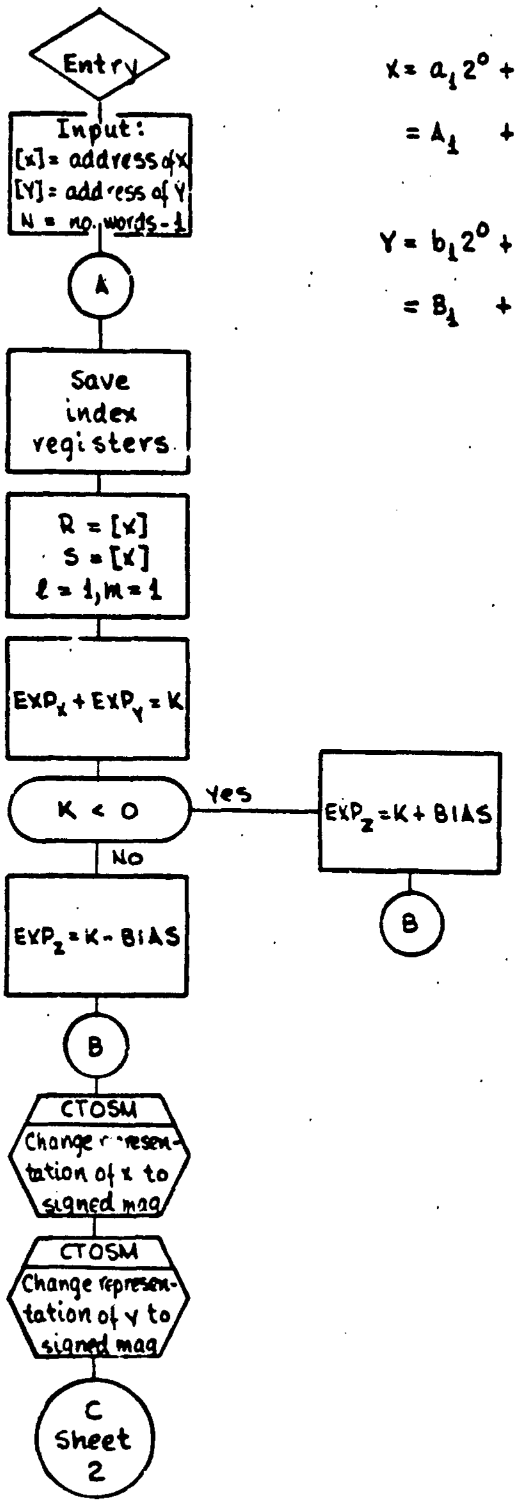
FLSB

$$X = a_1 2^0 + a_2 2^{-15} + \ldots + a_t^{-15(2t+3)}$$

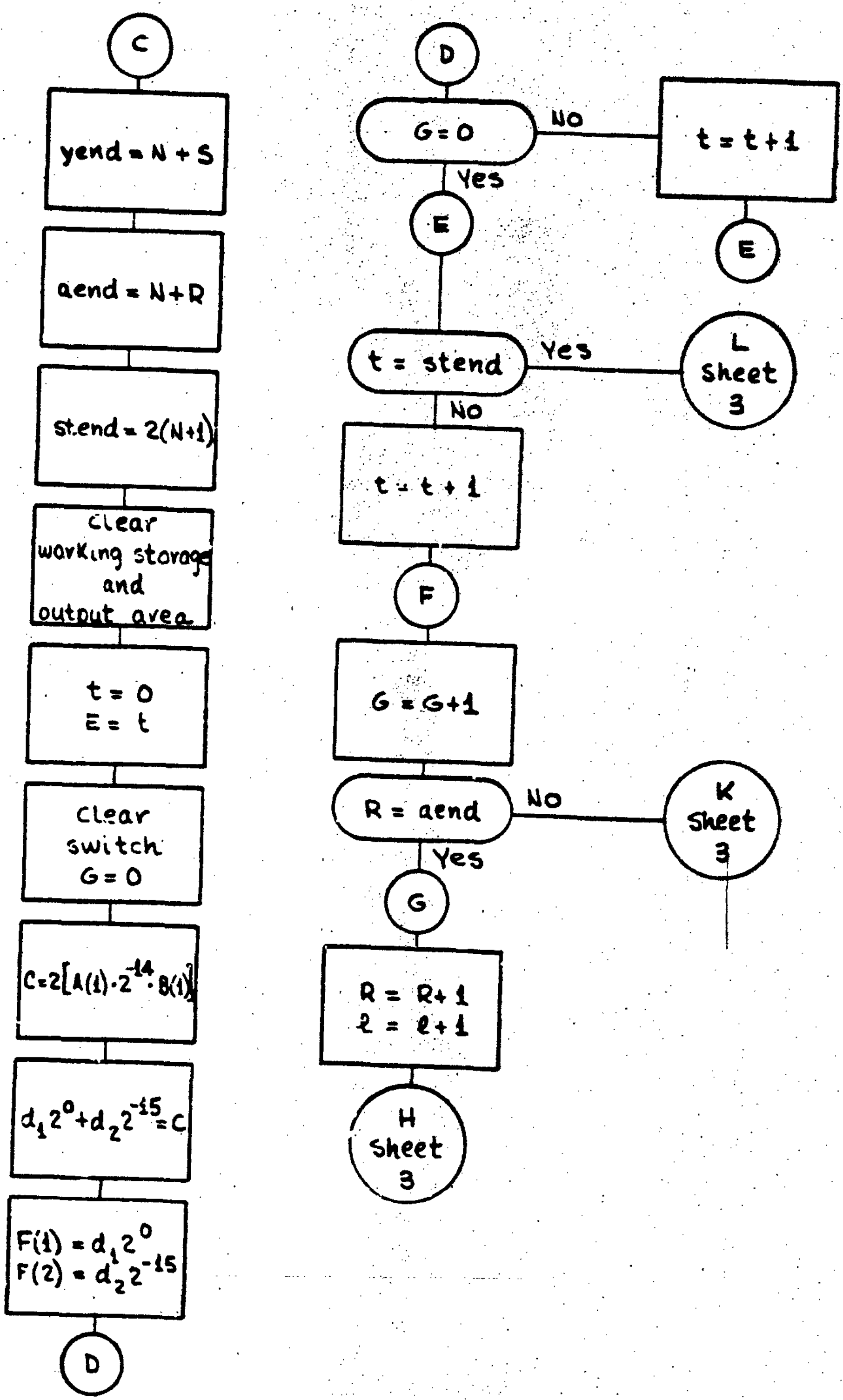
$$= A_1 + A_2 + \ldots A_{A+1}$$

$$Y = b_1 2^0 + b_2 2^{-15} + \ldots + b_s^{-15(s-1)}$$

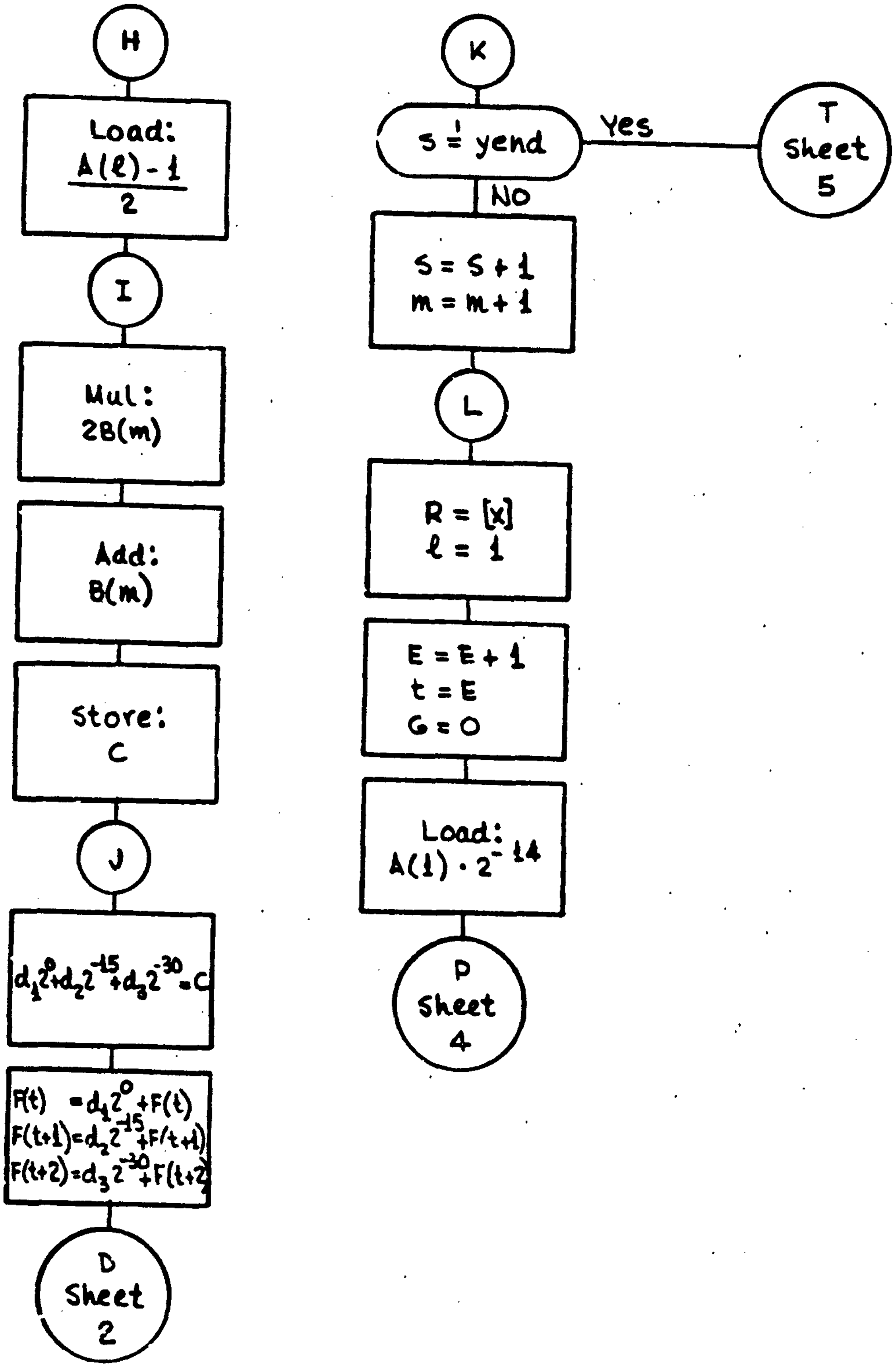
$$= B_1 + B_2 + \ldots + B_{2n+1}$$



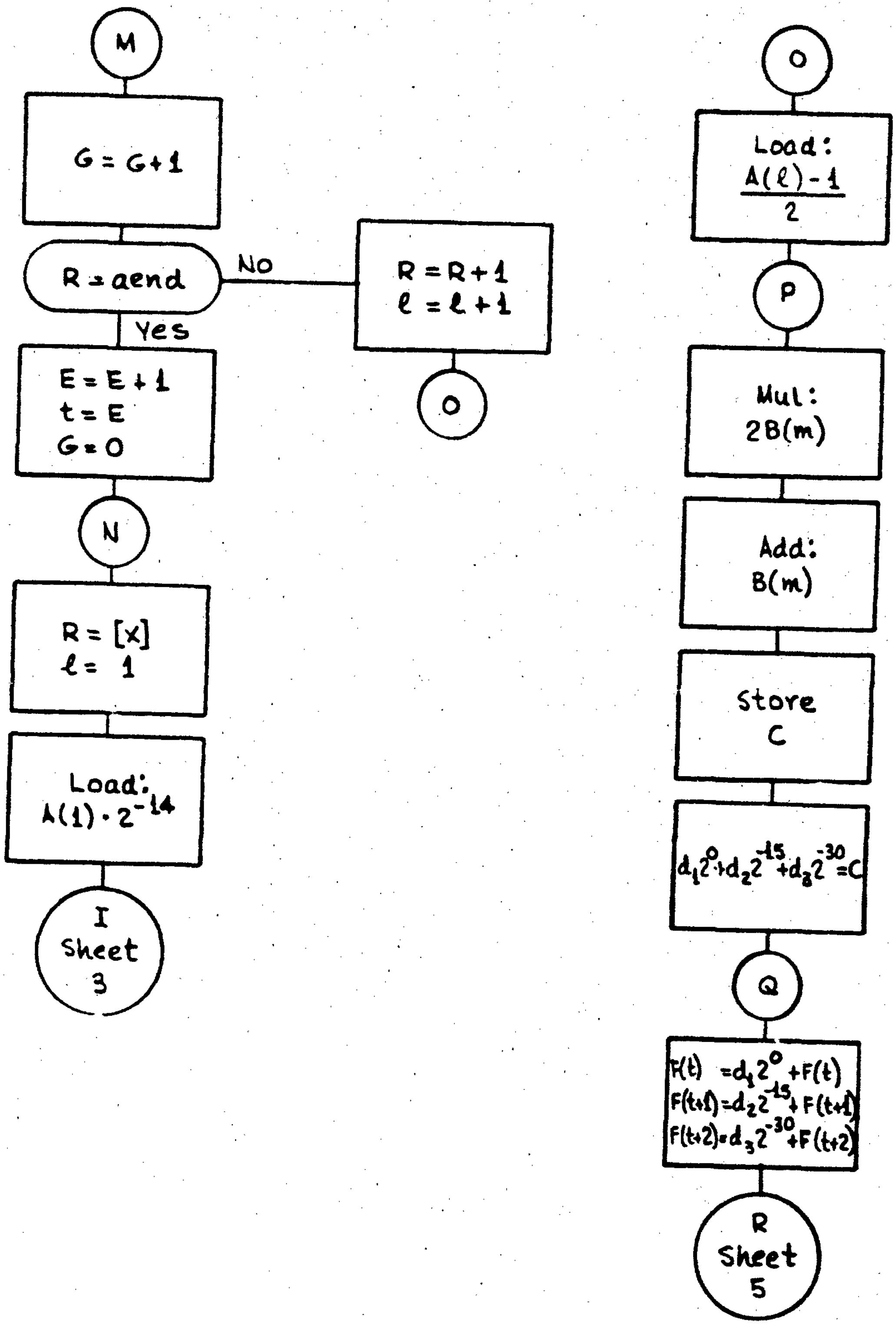
FLTMUL
Sheet 1 of 6



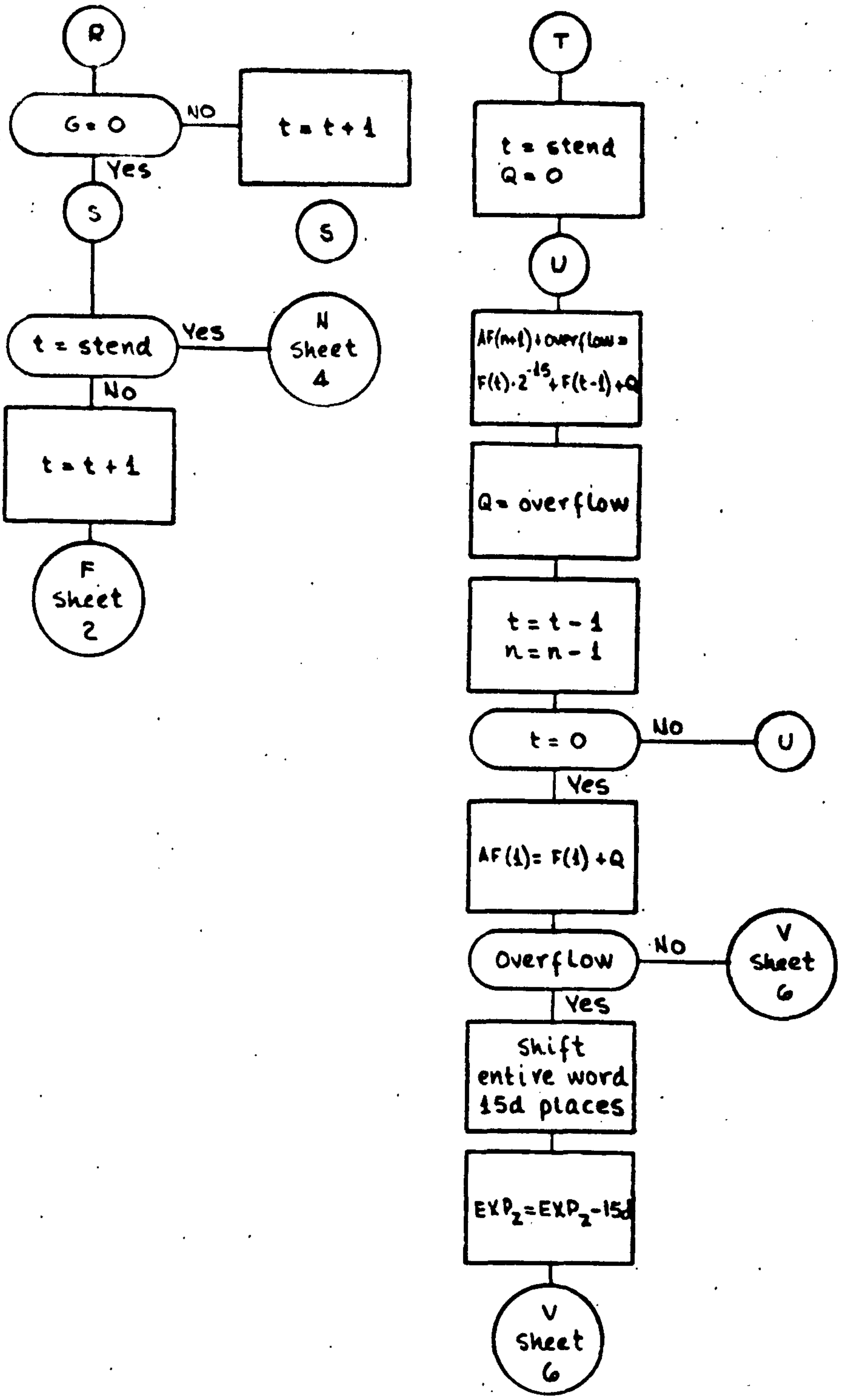
FLTMLL
Sheet 2 of 6



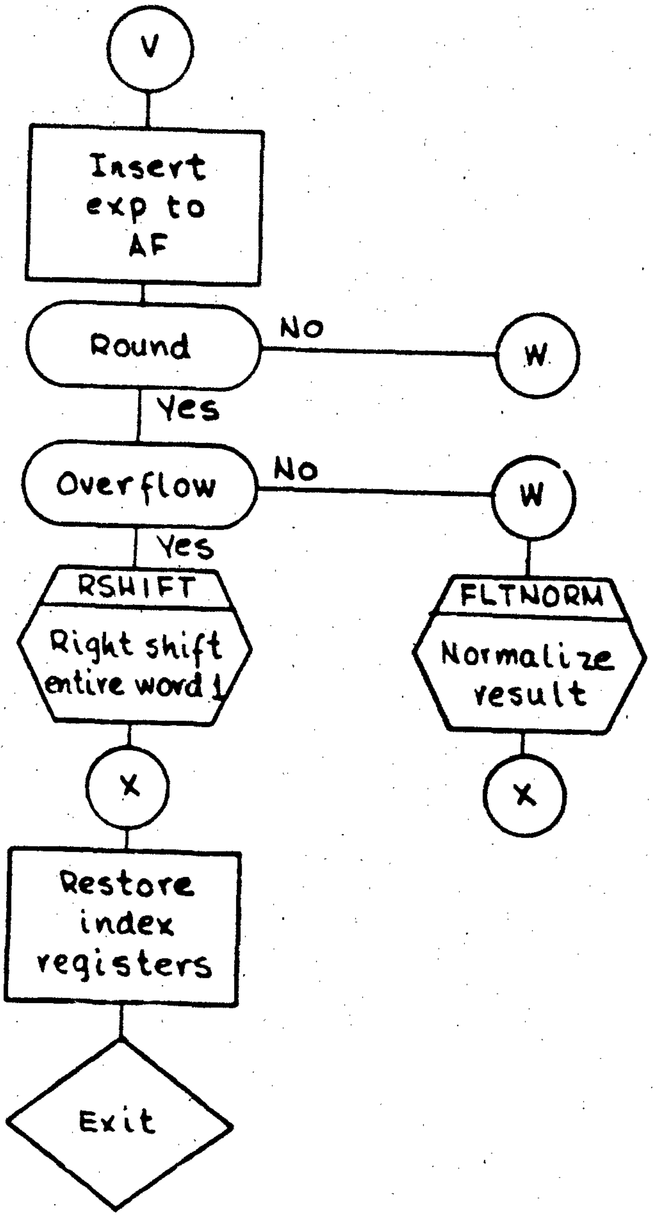
FLTMUL
Sheet 3 of 6



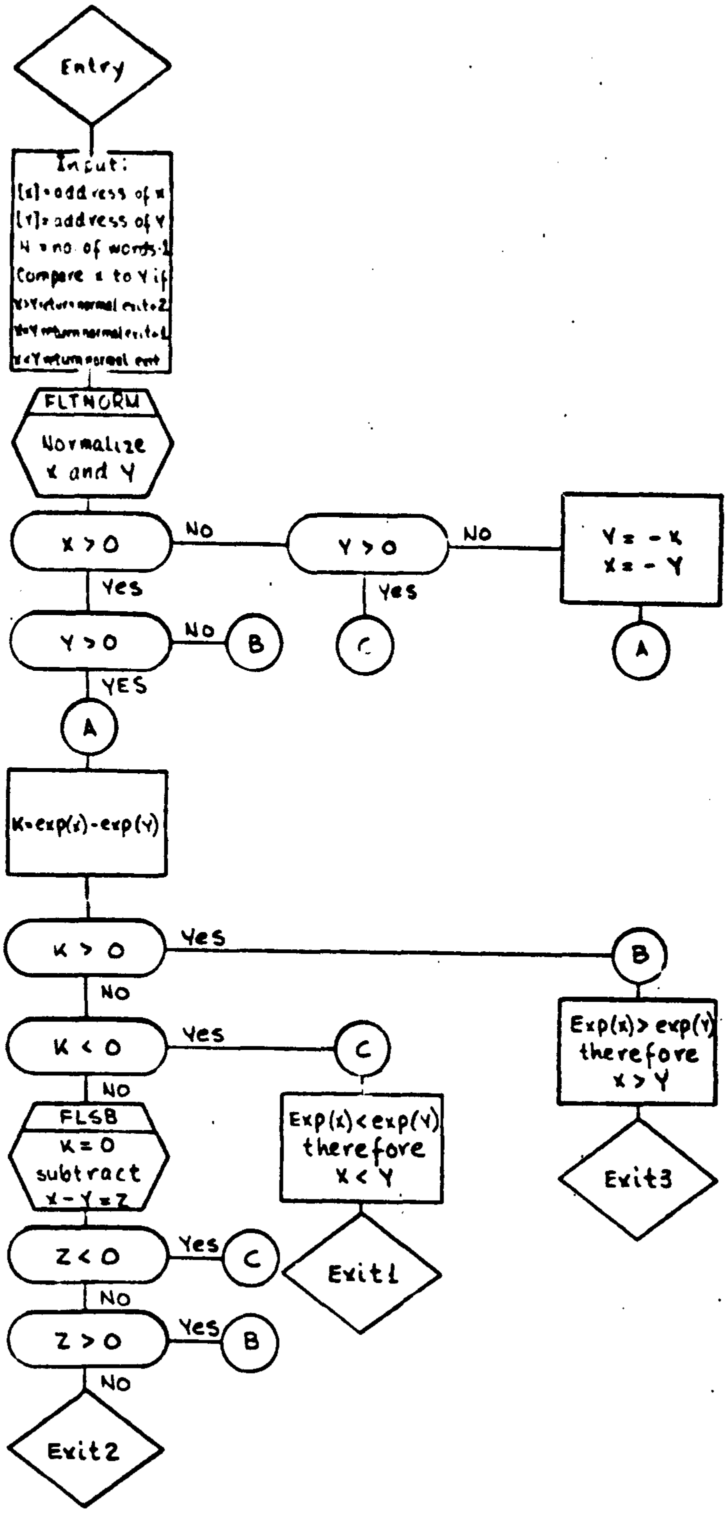
FLTMUL
Sheet 4 of 6



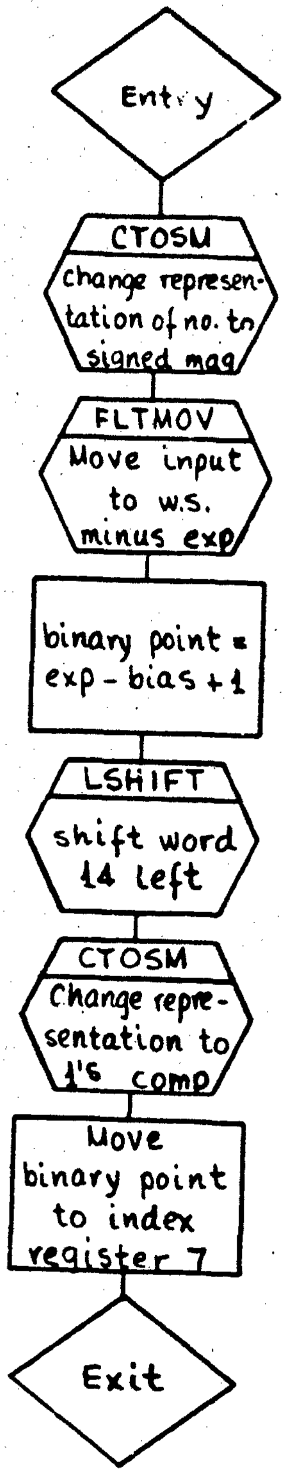
FLTMUL
Sheet 5 of 6



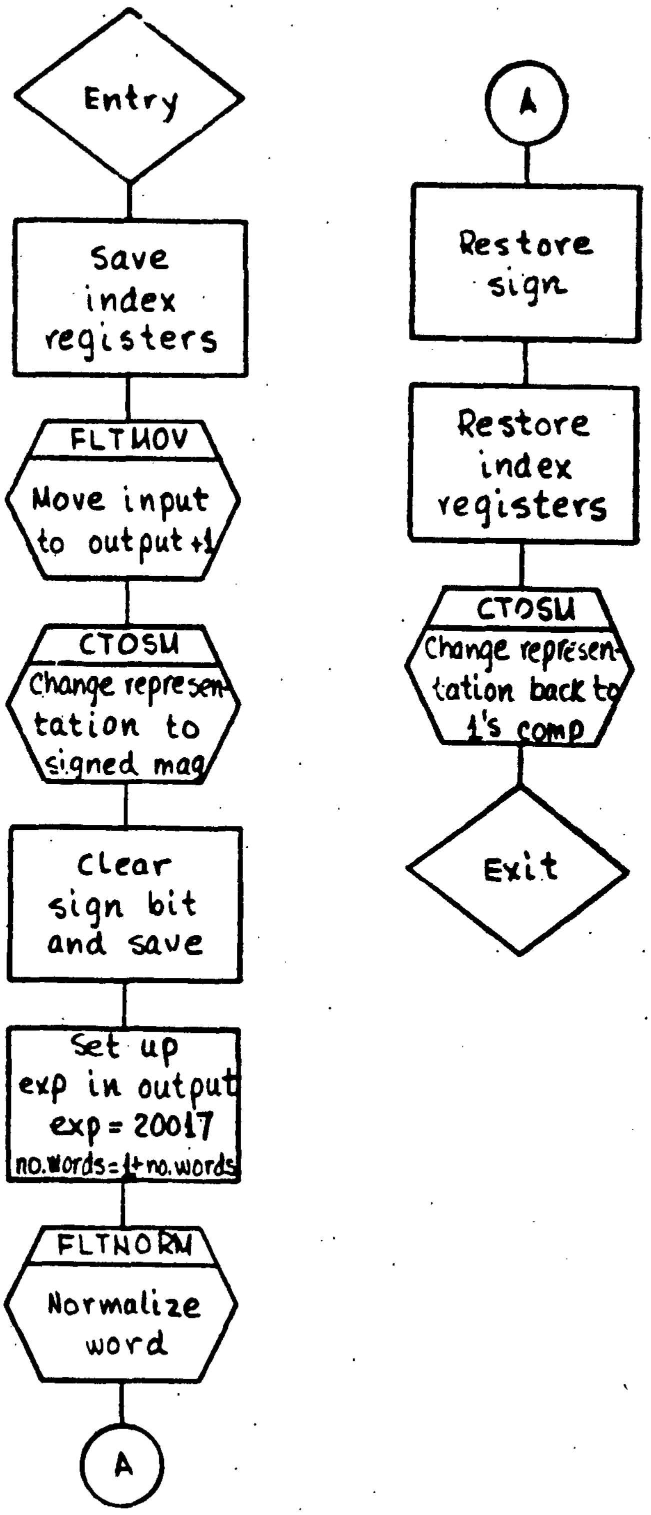
FLTMUL
Sheet 6 of 6


Entry
Input:
[x] = address of x
[Y] = address of Y
N = no. of words-1
Compare x to Y if
x>Y return normal exit+2
x=Y return normal exit+1
x<Y return normal exit
FLTNORM
Normalize x and Y
x > 0
NO
Yes
Y > 0
NO
Yes
Y = -x
x = -Y
A
Y > 0
NO
B
YES
C
A
A
K = exp(x) - exp(Y)
K > 0
Yes
B
NO
K < 0
Yes
C
NO
Exp(x) > exp(Y) therefore x > Y
Exit3
FLSB
K = 0
subtract
x - Y = Z
Exp(x) < exp(Y) therefore x < Y
Exit1
Z < 0
Yes
C
NO
Z > 0
Yes
B
NO
Exit2

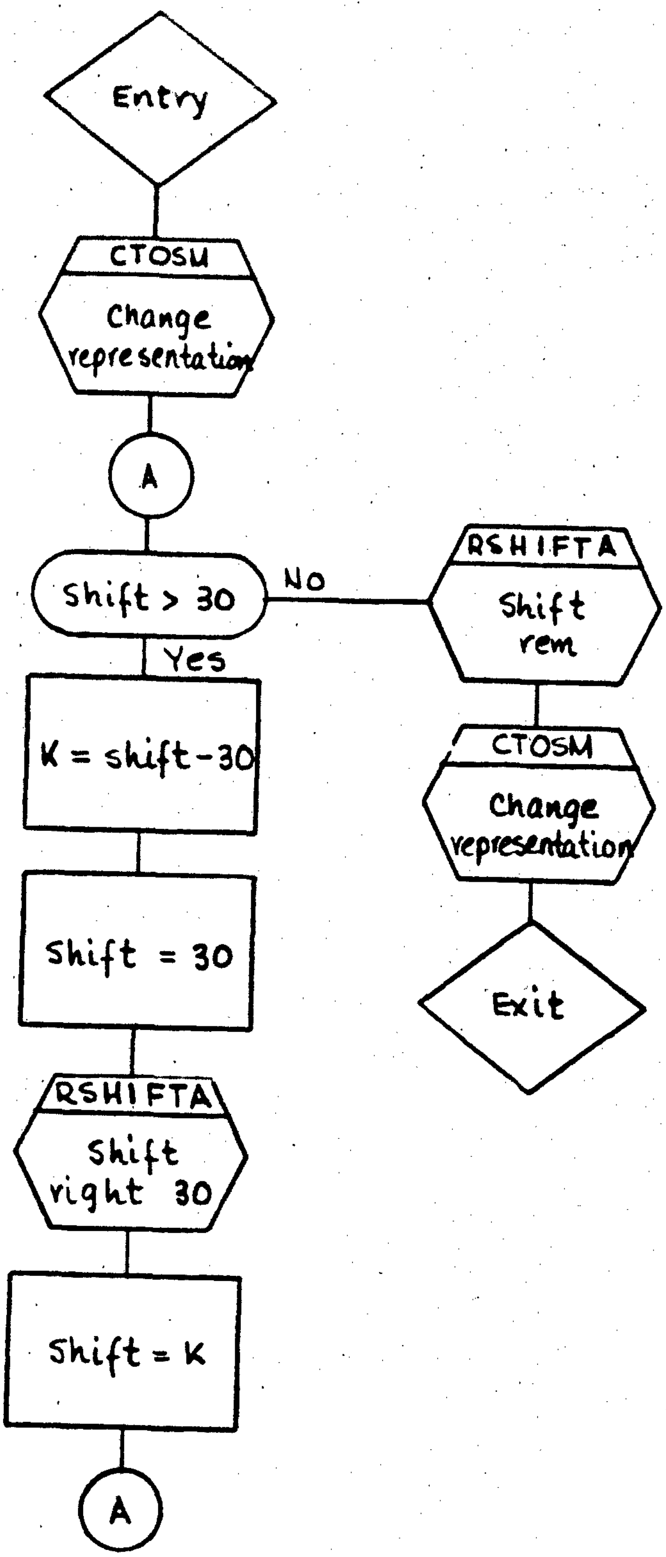
FLTCOM


Entry
CTOSM
change representation of no. to signed mag
FLTMOV
Move input to w.s. minus exp
binary point = exp - bias + 1
LSHIFT
shift word 14 left
CTOSM
Change representation to 1's comp
Move binary point to index register 7
Exit

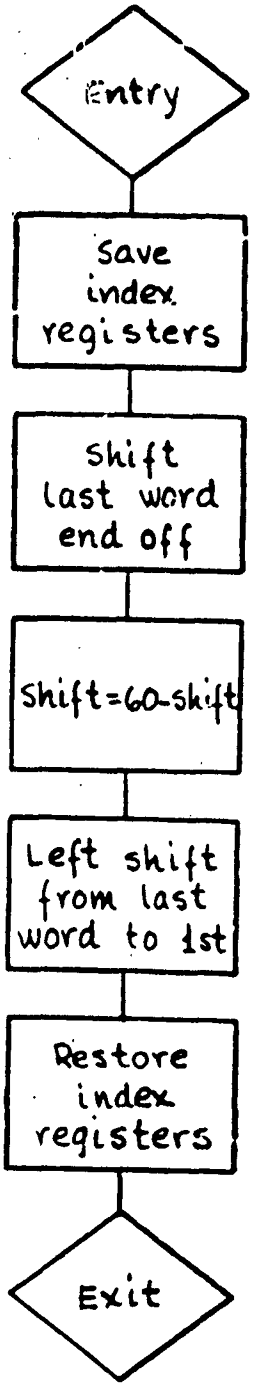
FLTFIX


Entry
Save index registers
FLTMOV
Move input to output+1
CTOSM
Change representation to signed mag
Clear sign bit and save
Set up exp in output
exp = 20017
no.words = 1+no.words
FLTNORM
Normalize word
A
A
Restore sign
Restore index registers
CTOSM
Change representation back to 1's comp
Exit

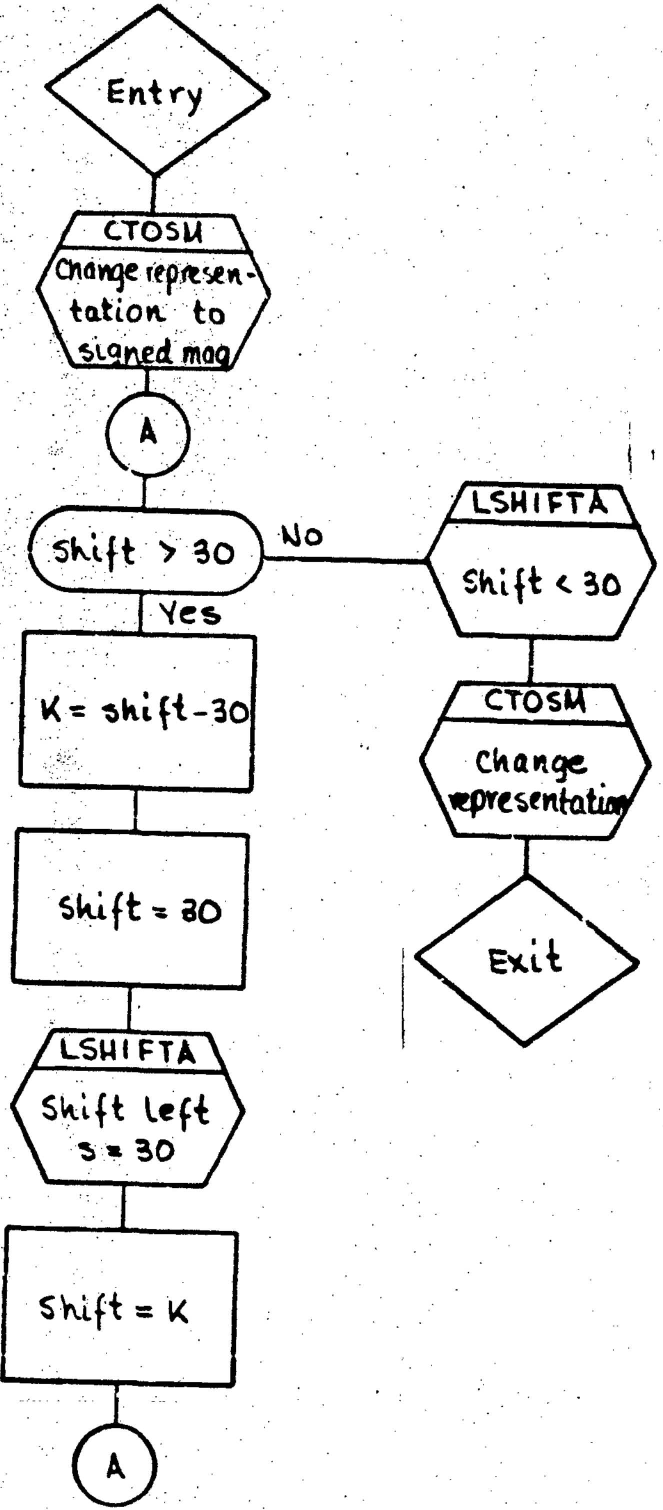
FXTFLT



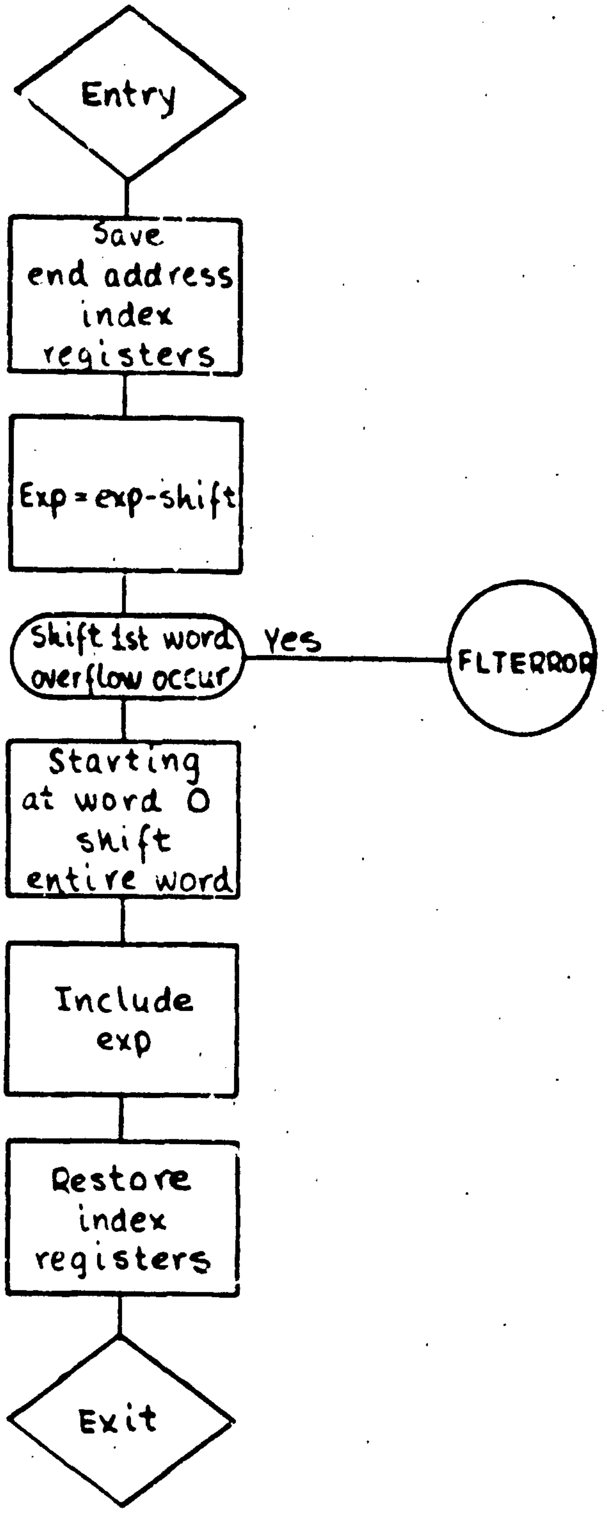
RSHIFT
Sheet 1 of 2



RSHIFTA
Sheet 2 of 2



LSHIFT
Sheet 1 of 2


Entry
Save end address index registers
Exp = exp-shift
Shift 1st word overflow occur
Yes
FLTERROR
Starting at word 0 shift entire word
Include exp
Restore index registers
Exit

LSHIFTA
Sheet 2 of 2

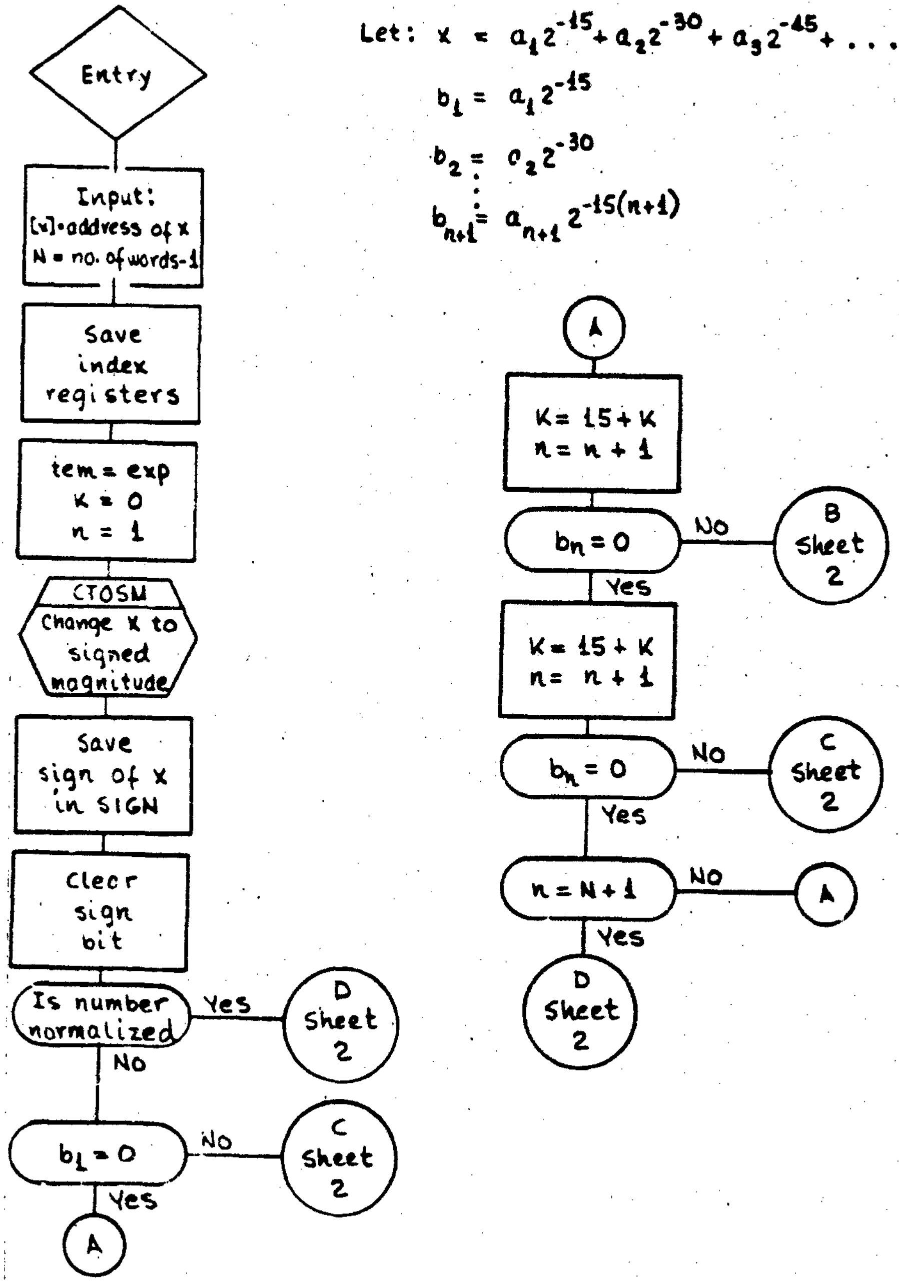
Let: $x = a_1 2^{-15} + a_2 2^{-30} + a_3 2^{-45} + \ldots + a_{n+1} 2^{-15(n+1)}$

$b_1 = a_1 2^{-15}$

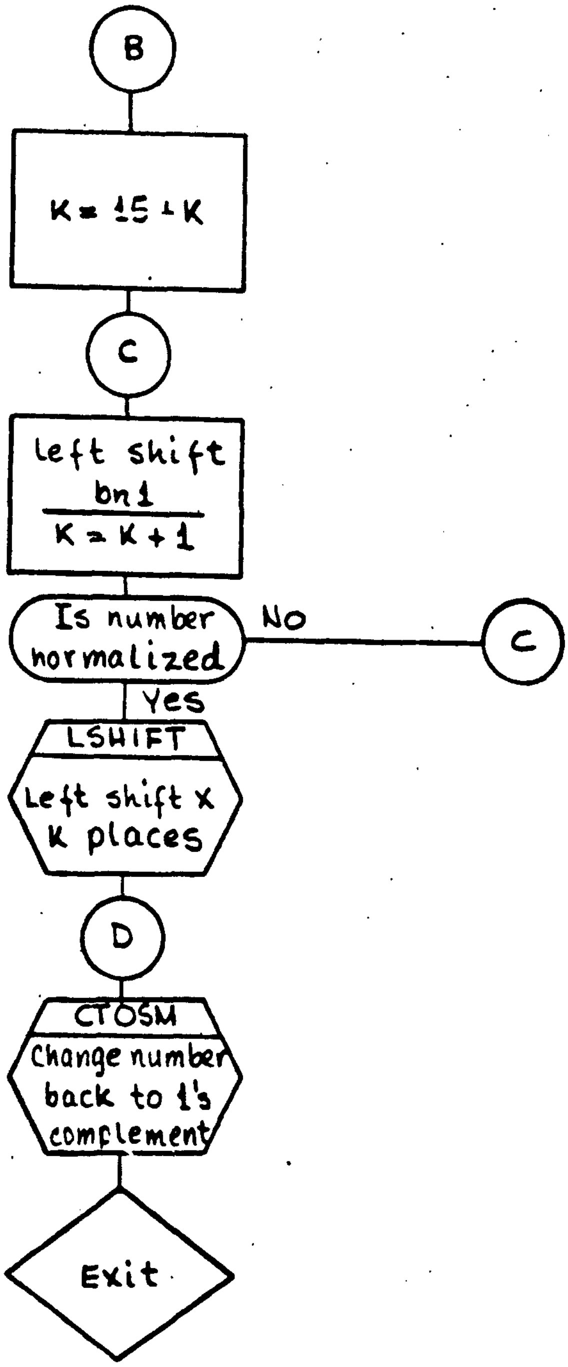
$b_2 = a_2 2^{-30}$

$\vdots$

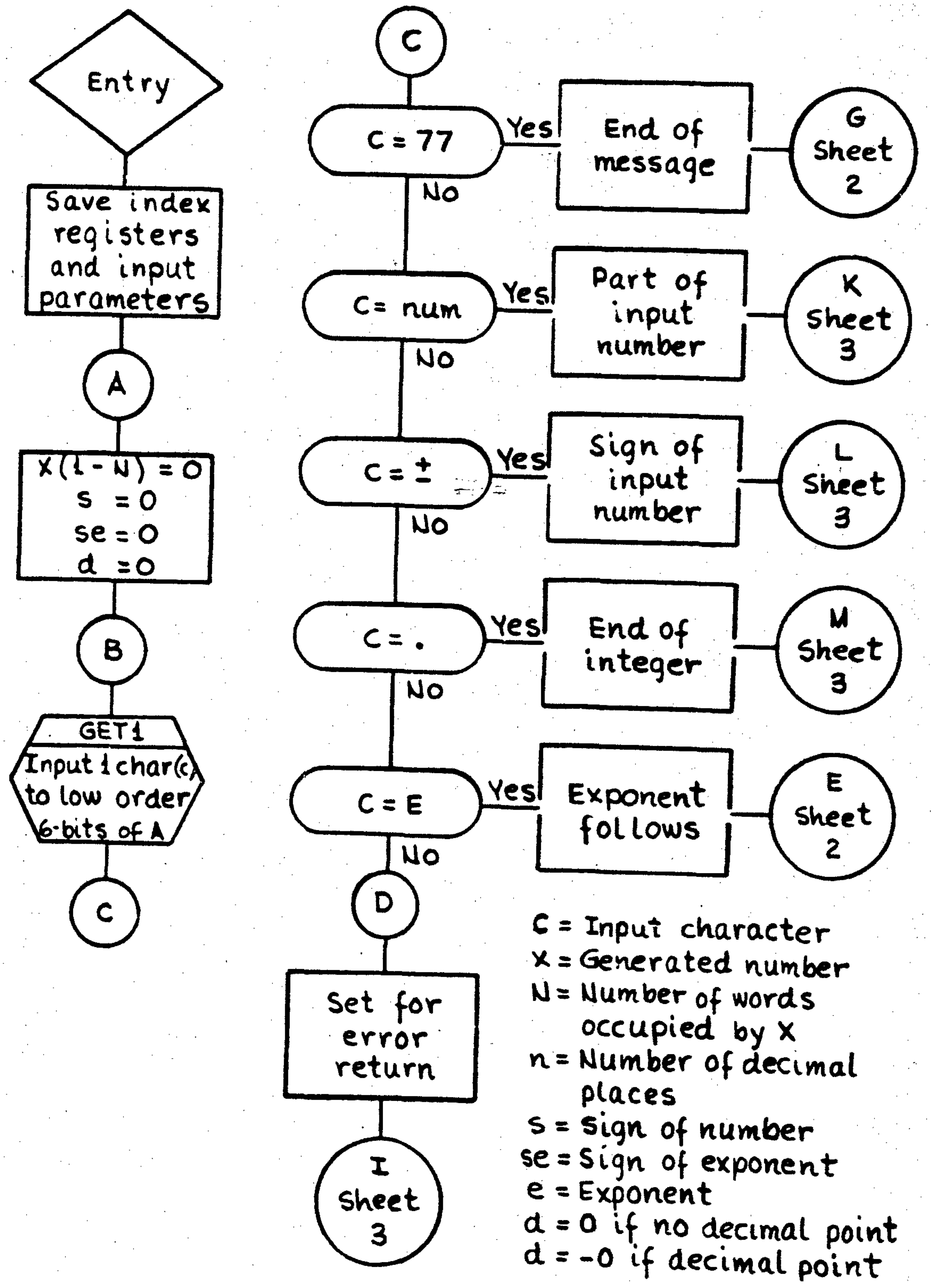
$b_{n+1} = a_{n+1} 2^{-15(n+1)}$



FLTNORM
Sheet 1 of 2

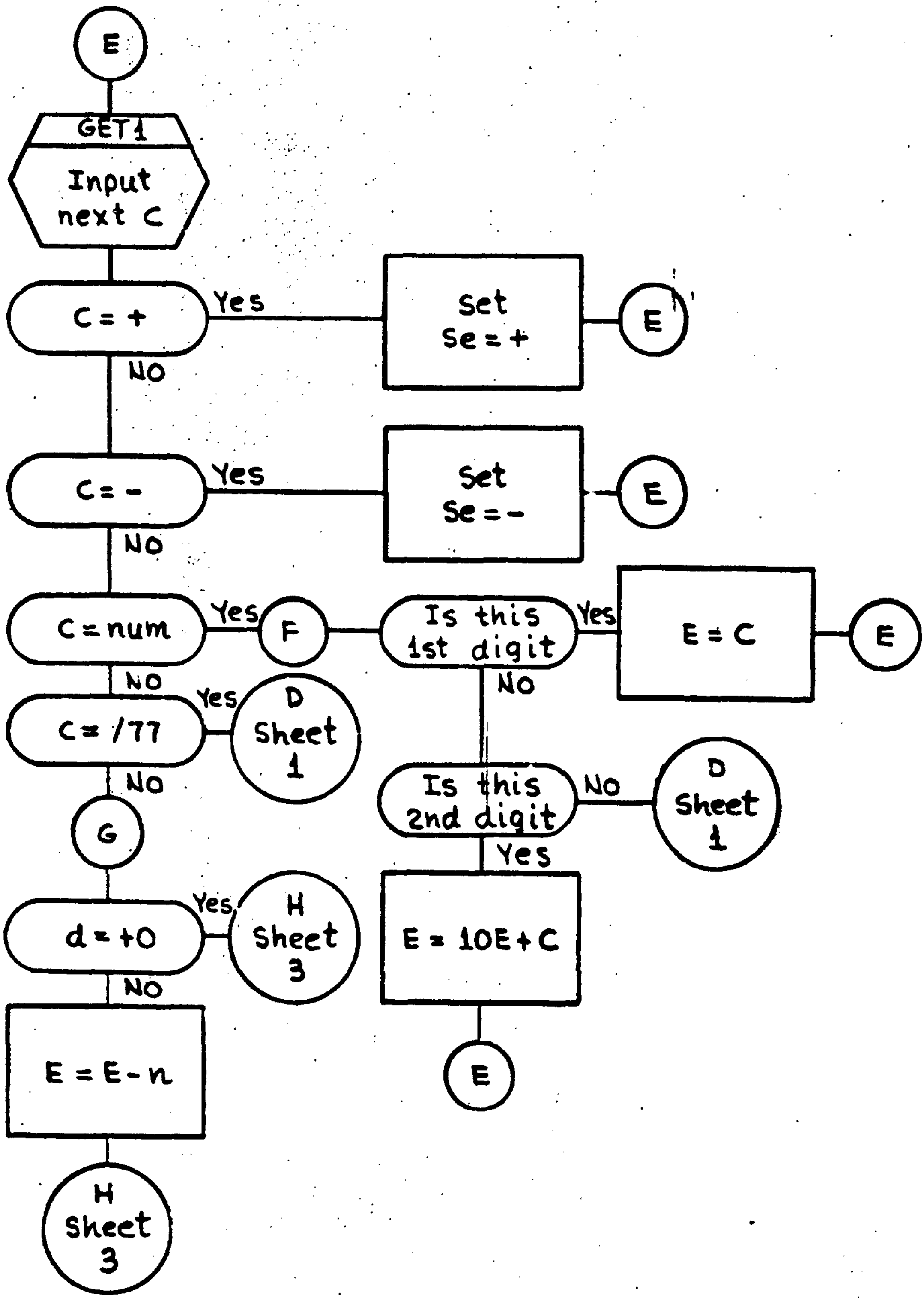


FLTNORM
Sheet 2 of 2

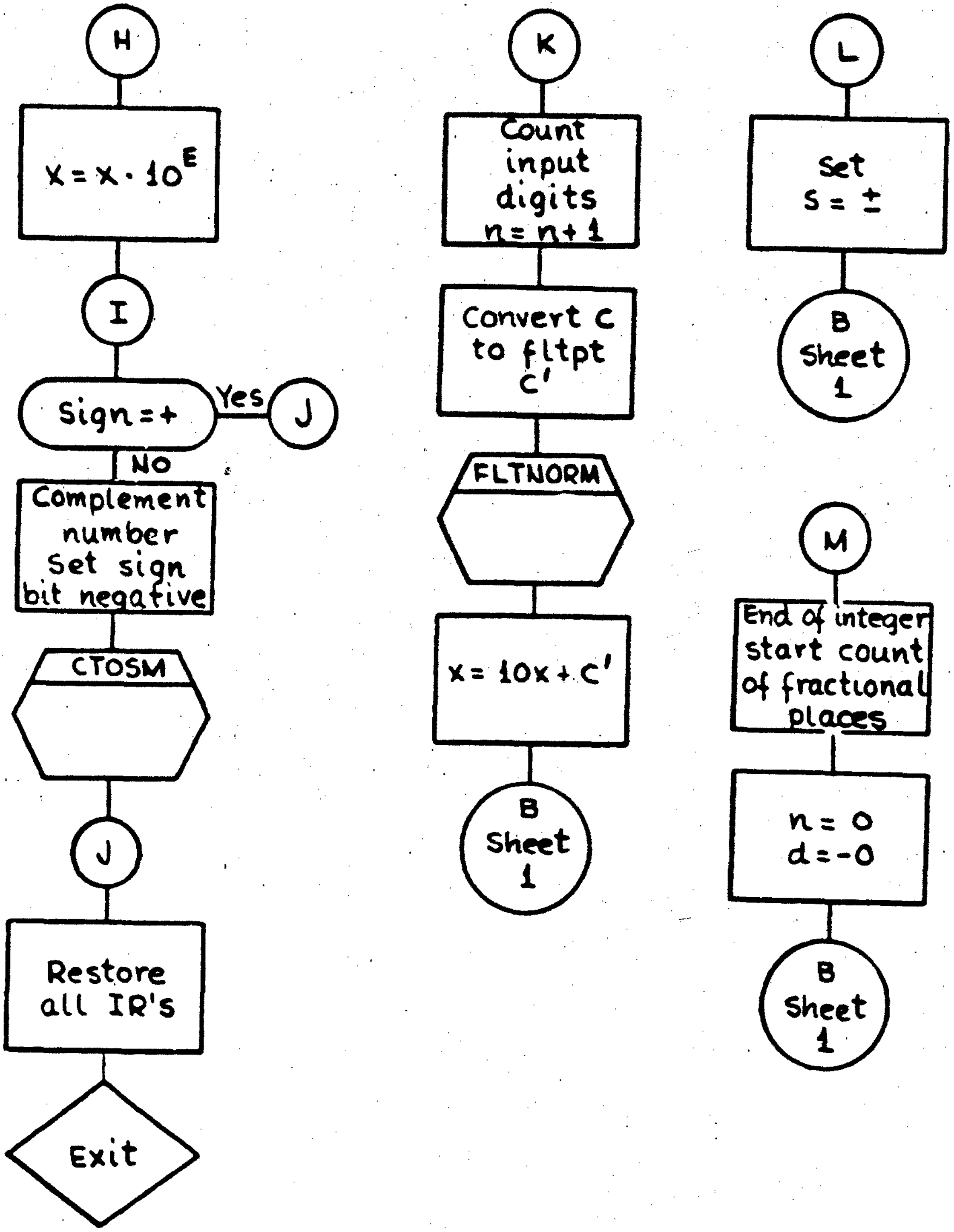


C = Input character
X = Generated number
N = Number of words occupied by X
n = Number of decimal places
s = Sign of number
se = Sign of exponent
e = Exponent
d = 0 if no decimal point
d = -0 if decimal point

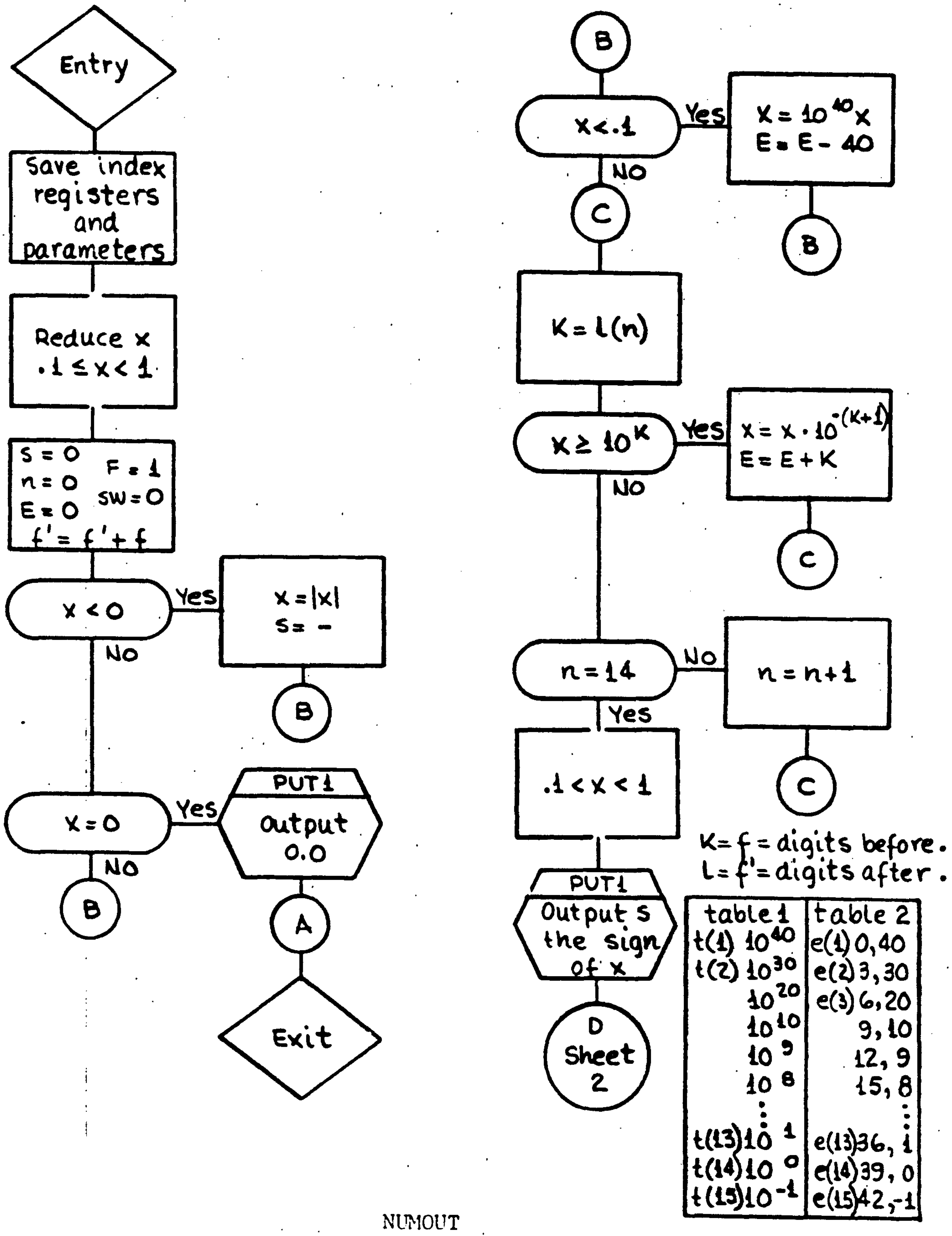
NUMIN
Sheet 1 of 3



NUMIN
Sheet 2 of 3



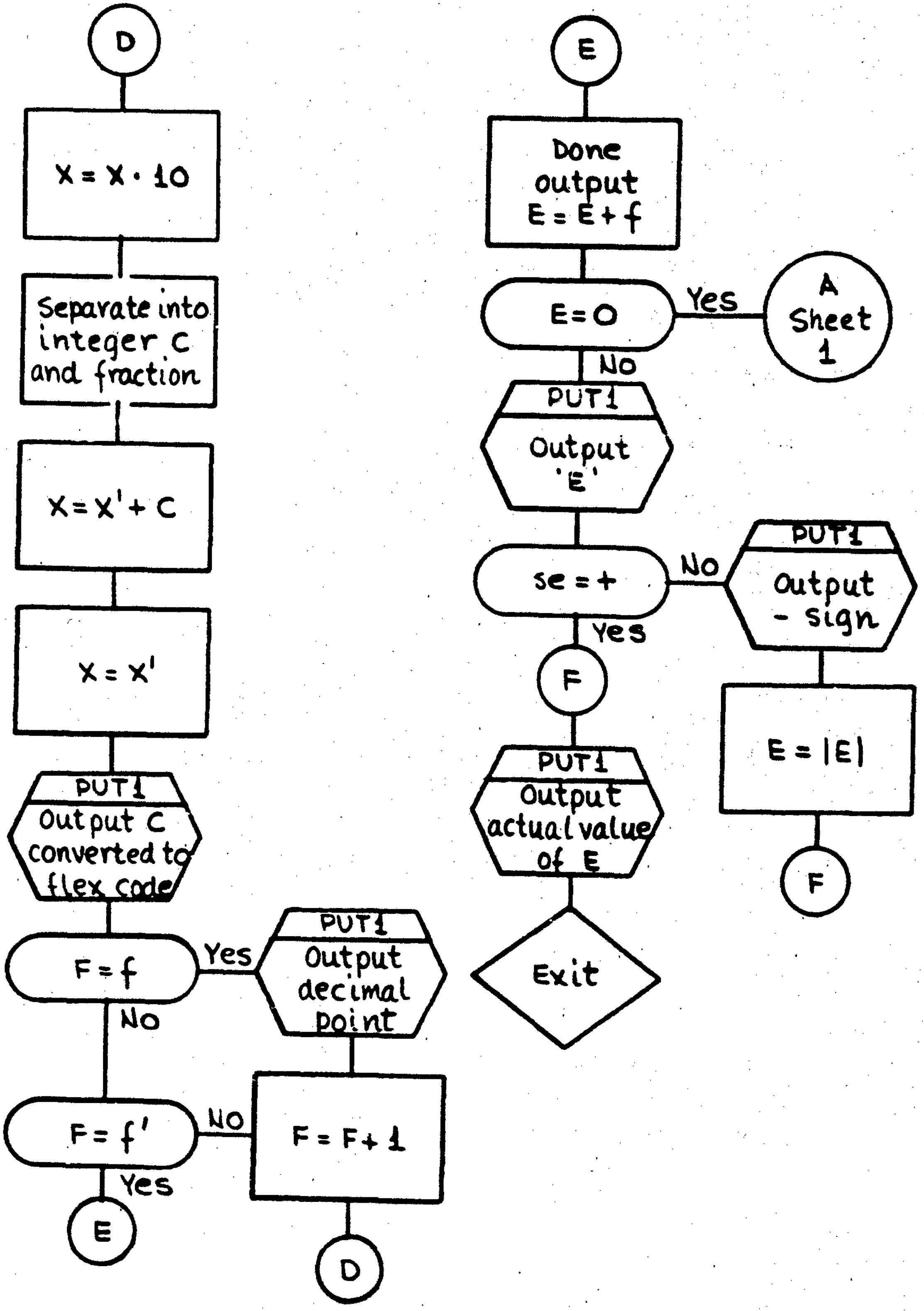
NUMIN
Sheet 3 of 3



K = f = digits before.
L = f' = digits after.

| table 1 | table 2 |
|---|---|
| $t(1)\ 10^{40}$ | $e(1)\ 0,40$ |
| $t(2)\ 10^{30}$ | $e(2)\ 3,30$ |
| $10^{20}$ | $e(3)\ 6,20$ |
| $10^{10}$ | 9,10 |
| $10^{9}$ | 12,9 |
| $10^{8}$ | 15,8 |
| ⋮ | ⋮ |
| $t(13)\ 10^{1}$ | $e(13)\ 36,1$ |
| $t(14)\ 10^{0}$ | $e(14)\ 39,0$ |
| $t(15)\ 10^{-1}$ | $e(15)\ 42,-1$ |

NUMOUT
Sheet 1 of 2



NUMOUT
Sheet 2 of 2

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13. ABSTRACT

This final report on Contract No. AF19(628)-5026 contains a summary of the five major tasks performed during the one-year duration of the contract. The work performed consisted of: 1) a variable-precision floating-point package for the solution of problems requiring very high precision, 2) extension of and improvements to the software system developed under an earlier contract, 3) assistance in the implementation and validation of a LISP Compiler, 4) development of a program for powerful manipulation of symbolic text (TECO), and 5) specification of a set of generalized display routines for visual communication with the computer. All work done related to the M-460 research computer at AFCRL.

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| COMPUTER SYSTEMS | | | | | | |
| FLOATING-POINT | | | | | | |
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